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ELECTRICAL EQUIPMENT OF ELECTRICAL STATIONS AND SUBSTATIONS

By

L. N. Baptidanov and V. I. Tarasov

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distribution unlimited.

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ELECTRICAL EQUIPMENT OF ELECTRICAL STATIONS AND SUBSTATIONS

By: L. N. Baptidanov and V. I. Tarasov

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

Page 1.

ELECTRICAL EQUIPMENT OF ELECTRICAL STATIONS AND SUBSTATIONS. In two volumes.

First volume.

L. N. Baptidanov and V. I. Tarasov.

Page 4.

Fundamental electrical equipment of electrical stations and substations publication the third, reworked.

It is allowed by the administration of the secondary special educational institutions of the Ministry of Higher education of the USSR as textbook for energy tecnnical schools.

Page 5 No Typing.

Page 6.

The description of many parts of electrical equipment is omitted on the assumption that with them the students will become acquainted in practical training.

In textbook is illuminated mainly new electrical equipment of domestic manufacture. In the part of the diagrams of electrical connections, constructions/designs of distributors and other questions in textbook are set forth predominantly those solutions, which obtained use/application in the Soviet Union or have the prospects for further putting into practice. Is given attention to

the contemporary tendencies in a matter of installation and equipment of electrics of the stations and substations in accordance with the technical policy of the directive organizations of the Soviet Union in this question.

In appendices are given the characteristics of fundamental electrical equipment of domestic manufacture which can be used for exercises and during training design.

The material of present textbook, necessary for studying separate specialties, is determined by the program of the course of the corresponding specialty. The structure of textbook accepted makes it possible to easily isolate this material.

The authors hope that, as in the preceding/previous publications, the book will find use also as textbook for the students of the electrical specialties of the technical institutes where the course "electrical equipment of electrical stations and substations" is not profiling.

In the first volume are presented the general information about electrical stations, substations and systems and is in detail examined their fundamental electrical equipment (see further the content of volume).

The secondly that are referred the diagrams of the electrical connections, their own of need and construction/design of the distributors of electrical stations and substations, base of relaying and system automation and some other questions.

The preceding/previous publications of textbook is obtained each many critical observations and wishes from students and teachers of different educational institutions, and also from the technical-engineering workers of power systems and planning organizations. All these observations and wishes of the readers the authors accepted with appreciation and, as far as possible, they considered during the treatment/processing of textbook. The authors hope also for further creative friendship with their readers, and all observations about the content of textbook and the procedure of the presentation of separate questions will accept with appreciation.

These wishes and observations we request to guide aiming at Gosenergoizdat: Moscow, Zh-144, Shlyuzovaya quay, 10.

In conclusion the authors express heart appreciation to all institutions and people, politely making available to them a number of valuable materials.

In the first volume by V. I. Tarasov they are written §22-7 and to chapter 23. Fntire other is written by L. N. Baptidanov.

Authors.

Pages 7-8. No Typing.

Page 9.

Chapter One.

ELECTRIFICATION OF THE USSR.

1-1. Electro-energetics of pre-revolutionary Russia.

The wide and diverse use/application of electric power in all fields of national economy and mode of life is explained by the series/row of its very essential advantages in comparison with other forms of the energy: possibility of economical transmission to considerable distances, simplicity of conversion into other forms of energy (thermal, mechanical, light, chemical, etc.), simplicity of distribution between any number of users of any power, etc.

High value has the capability of use for the production of electric power of the local fuels/propellants (brown coal, peat, schist, etc.), which contain a large quantity of moisture and incombustible substances and which possess small calorific value whose transport up to considerable distances is economically unsuitable, and also energy of rivers for installing the hydroelectric power plants, which develop cheap electric power.

It is difficult to visualize the life of contemporary society without electric power, the society whose economic and cultural development in many respects is caused by the precisely wide application of electric power.

Russian scientists and engineers greatly much made both in the region of developing theoretical questions of electrical engineering and in the region of the practical use/application of electricity in industry and for illumination.

The discovery/opening electric arc by V. V. Petrov (1802), invention by P. N. Yablcchkov electrical arc candle (1876) and by A. N. Lodygin incandescent lamps (1873-1874) initiated to the use/application of electricity for purposes of illumination.

Creation by acad. B. S. Jacobi and the first in practice applicable electric motor with rotary motion (1834-1837), invention by them galvanoplastics (1838), invention by N. N. Benardos the electric welding of metals (1882) placed the basis of the industrial use of electric power.

The work of the academicians E. Kh. Lentz and B. S. Jacobi into

field of the theory of electrical machines, establishment by E. Kh. Lentz the reciprocity principle of electrical machines (1833-1838), development by Yablochkov, Poleshko, Chikolov, Lachinov, etc. of the original constructions/designs of the electrical machines of direct and alternating current initiated to the creation of the electrical machines, suitable for industrial operation.

In Russia were carried out also the first experiments of electric transmission up to distance (F. A. Pirotskiy, 1874-1876) and are for the first time developed the theoretical bases of electric transmission up to great distances (D. A. Lachinov, 1880).

Thus, to the middle of the 80's were created all technical capabilities for transition/junction to the centralized power supply. Begins the installation of the power plants, which obtained at that time the name of the power houses.

The first power houses of direct current with a power of into several ten, but later several hundred kilowatts were constructed in the 80th and in the beginning of the 90's in Moscow, Petersburg, tsarist village (now g. Pushkin) and in the series/row of other cities. These power plants barely had power load, and only since 1892 when they were started electrical trolley in Kiev (first trolley in Russia), appears certain power load in the stations of direct

current.

The small voltage of the stations of direct current (110-220c) limited a radius of their action, and thereby also their power. Different attempts at the increase in the radius of action of the stations of direct current by increasing the voltage of the generator, series connection of generators, use/application of storage batteries in the places of the consumption of electric power, etc. proved to be little economical and very complicated and therefore propagation did not obtain.

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The power plants of single-phase alternating current for the first time arose in connection with the use/application of candles of Yablochkov. However, initially alternating current did not obtain any considerable use/application, since it was insufficiently studied. Moreover, in those year yet were not designed suitable for practical purposes alternating-current motors.

Tendency toward of the increasing centralization of power supply and the economic difficulty of achieving this or direct current again forced to turn to alternating current. The invention of power transformer (P. N. Yablochkov, 1876) offered the possibility of

applying alternating high-tension current and considerable increase in the radius of action of power stations.

The first power houses of single-phase alternating current by voltage 2-2.4 kV were constructed in Odessa (1887), tsarist village (1890), Petersburg (1894) and series/row of other cities.

By critical moment/torque in the development of power supply generally and power plants was in particular creation during the years 1888-1889 by outstanding Russian engineer M. O. Dolivo-Dobrov the system of three-phase alternating current. With it were for the first time created three-phase alternators, three-phase transformers and, which is especially important, three-phase asynchronous electric motors with the short-circuited and phase-wound rotor. The excellent qualities of asynchronous electric motors offered the possibility of their widest use/application into industry, possibility of the conversion of industry on the new, more advanced energy base. Three-phase current proved to be technically and economically more advisable for the realization of remote electric power lines.

In 1891 M. O. Dolivo-Dobrov constructed the first three-phase electric power line by voltage 15 kV and length of 170 km from Laupheim to Frankfurt-on-Main, which demonstrated the indisputable advantages of the three-phase current for transmission to great

distances with high voltage. Line was supplied from generator in power 230 kVA by voltage 95 c through the step-up transformer.

The advantages of three-phase current proved to be such considerable that already with the second half the 90's was begun the wide construction of the power plants of three-phase current and the gradual displacement by them of the stations of single-phase and direct current. For a direct current remained the comparatively limited field of application - different electrochemical processes (electrolysis, galvanoplastics, etc.) and electrification of rail transport. In this case direct current, as a rule, they began to obtain not from the special stations of direct current, but by the transformation of three-phase current into constant with the aid of dynamotors and single-armature converters.

Russia's first power plant of three-phase current in power 1200 kVA was constructed by eng. A. N. Shchensnovich in 1893 in Novorossisk. Station was intended for the electrification of elevator.

In 1896 V. N. Chikolev and R. E. Klasson realized an electrification of the Okhten powder plant in Petersburg from hydroelectric power plant on r. Okht, on which were established/installed two generators in total power 295 kW with

voltage 2050 in. This was Russia's first power plant of three-phase high-tension current.

The fundamental builder of Okhten installation, the outstanding Russian engineer R. E. Klasson not only created the new type of the power plant, which was subsequently sample/specimen during the installation of the stations of three-phase current, but also for the first time in the world was carried out the composite power supply of plant on the base of the new technique of three-phase current.

In 1897 on Lenskiy gold mines was constructed the electric power line of three-phase current by voltage 10 kV.

From this time in Russia was begun the development of the electrical devices of three-phase current, the widespread introduction of electric motors into industry and its reconstruction on the basis of electrification.

In Moscow in 1897 was started the new power house of the three-phase current of "Society 1886" (now 1st MGES) in power 3300 kW with voltage generators 2.1 kV, that supplied by electric power of users in a radius to 5 km. The builder of this station was also R. E. Klasson, who continued the initiated by it on Okhten installation introduction of new technical principles into electrical engineering.

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Petersburg's first station of three-phase current (now 1st LGES) in power 5000 kW with generator voltage 2 kV was started in 1898.

The power plants of three-phase current were constructed also in Kiev, Riga, Kharkov and series/row of other cities.

By important stage in the development of power supply three-phase current was installation during the years 1900-1902 R. E. Klasson with the participation of L. B. Krasin in Baku of two large/coarse for those times power plants (now "Red Star" and im. L. B. Krasin), which worked on the general/common/total electric system by voltage 20 kV, from which was realized the power supply of petroleum trades. Later than the electric system by voltage 20 kV they were installed in Donbass and Bryansk.

Characteristic for the development of thermal power plants in the first decade of XX century was all increasing use/application by them of steam turbines, possessing the series/row of essential advantages in comparison with steam engines (is more economical, more reliable, more the rotational speed, are less overall sizes, are

simpler drift/care, etc.), and in connection with this a rapid increase in the power of separate power plants.

Since powerful thermal power plants require for their work of a large quantity of water and supply of a large quantity of fuel/propellant, then during this period powerful/thick stations begin to install out of the territory of cities - in their outskirts or near major enterprises.

Subsequently the successful development of the electrical industry, especially in the region of electrical equipment of high voltages, revealed the possibility of transition/junction to the new system of power supply from the powerful/thick district thermal power plants, planned near the places of the deposits of fuel/propellant, and also from powerful/thick hydroelectric power plants, with the transmission of manufactured by them electric power to users along the electric power lines of high voltage.

During the years 1912-1914 R. E. Klasson was constructed district power plant in power 15,000 kW in 70 km from Moscow, obtained name "power transmission" (now GRES [ГРЭС - state regional electric power plant] the name of Klasson). From this station electric power was transmitted to Moscow along the transmission line by voltage 70 kV. This was first in the world local exchange on peat. However, the

construction of district power plants was swept in our country only after the great October Socialist Revolution.

After feeding/conducting the totals of the development of electro-energetics in pre-revolutionary Russia, it is necessary to note that, in spite of the enormous contribution of the Russian scientists and engineers to a matter of development the electro-energeticists, the general/common/total level of the electric power economy of Russia it was very low. So, the installed power of all power plants of Russia in 1913 composed only of approximately 1100 MW in the production of the electric power of approximately 2 billion kW•h, or about 14 kW•h to man per annum. On the output level of electric power Russia occupied the 15th place in the world.

Powerful/thick hydroelectric power plants in Russia it was not at all; the total power of small/fine hydroelectric power plants was only 16 MW with annual output approximately 40 mln. kW•h.

All thermal power plants were urban either industrial and worked at oil or high-energy long-range stone angle - donets and even imported.

The only power plant, which had district value and which worked on local fuel/propellant - peat, was power plant indicated above

"Elektroperedacha".

The power of the majority of thermal power plants was small - hundreds of kilowatts. Only several thermal power plants available capacity on 30-40 MW. The maximum power of steam turbine units was 10 MW, boiler steam capacity did not exceed 20-30 t/h at pressure of vapor to 12-16 atm(abs.) and temperature of its overheating to 300-350°C.

The efficiency/cost-effectiveness of power plants was low. So, on the power plants of the general/common/total use, which were most large/coarse and relatively more economical the average/mean specific consumption of cool equivalent [1] it composed approximately/exemplarily 1100 g/kW•h, to which corresponded heat rate 1.1•7000=7700 kcal/kW•h and the average efficiency of stations (860/7700) 100~~11o/o.

FOOTNOTE [1]. As cool equivalent they accept fuel/propellant with enthalpy 7000 kcal/kg. ENDFOOTNOTE.

The total length of electric power lines by voltage 11-70 kV composed only of approximately 185 km.

The fundamental reasons for the such weak energy basis of pre-revolutionary Russia were its industrial backwardness and almost full/total/complete absence of its own energy industry.

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1-2. Electrification of the USSR during the years 1917-1958.

The economic base of Communist society is heavy industry - industry, which produces the means of production, and first of all machine-building, metallurgical, fuel, energy, etc.

Indispensable the conditions for the development of heavy industry and, consequently, also other branches of national economy are wide mechanization and automation of production processes, continuous perfection of instruments and means of labor, permanent use/application of the newest technology, which gives the greatest savings of the expenditures of public work and every possible its facilitation.

The newest technology is compulsorily connected with electric power, this most ideal by form energy, which makes it possible to very simply and economically realize mechanization of labor.

Only on the basis of the use/application of electric power is possible the creation of contemporary automatic machines, large/coarse flow and automated productions, hundreds times of those increasing labor productivity and facilitating the work of man.

V. I. Lenin repeatedly emphasized the converting role of electric power, its value for the industrialization of the country, for the construction of Communist society. In 1921 he wrote: "The sole material base of socialism can be the large/coarse machine industry, capable of reorganizing and farming... Appropriate level of the newest technology and capable of reorganizing farming large scale industry is an electrification of the entire country" [1].

FOOTNOTE [1]. V. I. Lenin, works, publ. the 4ths, Vol. 32, page 434, 1952. ENDFOOTNOTE.

By electrification V. I. Lenin understood not the construction of separate power plants in different regions of the country, but the planned electrification of the entire country, all branches of national economy, including farming.

Attaching much importance to electrification of the country, the Communist Party and the Soviet government approached its realization in the first years after great October Socialist revolution as early

as the year of civil war and foreign intervention. During the subsequent years was swept the planned electrification of the entire country whose rates of the five-year period in five-year period rapidly grew.

Within the time of civil war and foreign intervention (1918-1920), the power system management of the country arrived into the large decline; in 1921 the electric energy generation composed only of 0.5 billion kW•h.

During April 1918 by the Council of Peoples' Commissars was accept the solution about the expansion of Moscow power plant "power transmission"; in the summer of 1918 was begun the construction of Volkhov hydroelectric power plant, in the fall of 1918 - a Shatura district power plant on peat, while during July 1919 - a Kashira district power plant at Moscow angle.

During February 1920 on the proposition of V. I. Lenin the session of VTsIK [ВЦИК - All-russian Central Executive Committee (1917-1936)] made a decision about the development of the plan/layout of Russia's electrification. Was formed the special board into composition of which entered the outstanding workers of the electrification of the USSR: G. M. Krzhianovskiy, M. A. Shatelen, G. O. Graftio, K. A. Krug, I. G. Aleksandrov, A. V. Winther, R. E.

Klasson, V. F. Mitkevich et al. under V. I. Lenin's management/manual the board developed the state plan of electrification of Russia - plan/layout of GOELRO [ГОЭЛРО.- State Commission for the Electrification of Russia] which on 20 December, 1920, on V. I. Lenin's proposition was affirmed by VIII by the All-Russian congress/descent of councils.

In his report at VIII the All-Russian congress/descent of councils V. I. Lenin spoke: "In my view, this - our second program of party/batch... Communism - this is the Soviet regime plus the electrification of the entire country" [2].

FOOTNOTE [2]. V. I. Lenin, works, publ. the 4ths, Vol. 31, page 482-484, 1952. ENDFOOTNOTE.

The plan/layout of GOELRO provided for an increase of the space of industrial production in the country approximately/exemplarily 2 times in comparison with 1913. This fundamental increase in the industry, medullary of entire plan/layout, was the planned during 10-15 years installation of 30 district power plants in different regions of the country with a total power of 1750 MW. Electric energy generation it was assumed to bring to 8.8 billion kW•h per annum. The plan/layout of GOELRO planned the wide use of local low-calorie fuel/propellant (peat, brown coals, etc.) and energy of rivers. The

total power of the planned hydroelectric power plants must be to be 640 MW, including Volkhov, two Svirsk, Dneprovsk.

The plan/layout of GOELRO installed the paths of the basic socialist retuning of the entire economy of the country. This was the first national-economic plan/layout of our socialist state.

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The first-borns of Soviet electrification they were: Kashira district power plant at Moscow angle (1922), Shatura district power plant on peat (1925), Leningrad district of electric power plant "Red October" on peat (1922), Volkhov (1926) and Zemo-Avchal'skaya (1927), hydroelectric power plant and many others.

During May 1922 was put into operation first grade in the USSR the electric power line by voltage 110 kV Kashira-Moscow.

The plan/layout of GOELRO was carried out to 1 January, 1931, i.e., in 10 years. The by this time installed power of all power plants achieved 2880 MW; electric energy generation for the year 1930 was 8.4 billion kW•h [1-1].

In the year of the realization of the plan/layout of GOELRO

primary attention was directed toward the installation of powerful/thick district thermal and hydraulic power plants.

Many industrial enterprises require for their technological process of a large quantity of thermal energy in the form of vapor or hot water (chemical plants, textile factories, etc.). Furthermore, a large quantity of thermal energy is required in cities and in enterprises for purposes of heating. With the power supply of users from district power plants their heat supply was accomplished from the local boiler installations, planned with enterprises and separate houses and worked, as a rule, on imported high-energy fuel/propellant. In connection with this it proved to be economically more advisable to pass to the composite centralized supply of the users of thermal and electrical from the heat and power plants (for greater detail, see § 2-2.).

The beginning of district heating in the USSR is pertained to the year 1924, when was fluffed the first central heating installation on one of the Leningrad power plants. In 1931 by TsK VKP (b) was carried out the special solution about every possible development of district heating. From this time the powering of users in the Soviet Union rests not only at region thermal and hydraulic stations, but also on heat and power plants. The power of the latter is determined, in essence, on the basis of the requirement of users

for thermal energy. Entire/all missing electric power is developed on district power plants.

Since the transmission of thermal energy up to large distances it was difficultly make as a result of the large heat losses in conduits/manifolds, then heat and power plants were installed in immediate proximity of the users of thermal and electrical energy - near or in the territory of cities and major enterprises.

Very rapidly power engineering of the USSR was developed in the year three first five-year plans. In pre-war 1940 the installed power of all power plants of the USSR achieved 11200 MW with the annual output of electric power of 48.3 billion kW•h [1-1 and 1-2].

Large damage to Soviet power engineering was plotted/applied in the course of the Great Patriotic War when in south and west of the country were destroyed 61 large/coarse power plant to the total power of 5000 MW, which was approximately 45o/o of entire prewar power of power plants of the Soviet Union. Furthermore, they were failing to 10 thousand km of the main-line electric power lines of high voltages and a very large number of different substations. Simultaneously during the years 1942-1944 in the East regions of the country were introduced on power plants of approximately 3400 MW of new power.

After the termination of war the power system management was developed with the intensive rates, and as long ago as in 1946 g. according to installed power (12,300 MW) and annual output of the electric power (48.6 billion kW•h) was achieved/reached level of 1940 to 1950 were restored/reduced all power plants, destroyed during war.

In 1958 all power plants of the USSR manufactured about 233 billion kW•h, or more than 1100 kW•h to man per annum. The installed power of power plants toward the end of 1958 was about 53,000 MW. Only in latter/last 7 years (1952-1958) the consumption/production/generation of the electric power increased more than 2.2 times, and the installed power of stations - approximately/exemplarily 2.4 times.

On the production of electric power of the USSR occupies the first place in Europe and the second place in the world - after the USA where in 1957 were manufactured electric power of 716 billion kW•h, or about 4250 kW•h to man per annum. The installed power of all power plants of the USA in 1957 exceeded 140,000 MW.

In 1958 in the industry of the USSR more than 90o/o machines (according to power) were given in motion by electricity. On the basis of electrification widely is mechanized not only entire complex of production processes, but also processes of auxiliary ones -

transport, loading-unloading, repair, etc. More than two thirds entire manufactured by power plants electric power are expended/consumed in industry.

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In the technological needs of industry (electrochemistry, electrometallurgy, etc.) are expended/consumed more than 26o/o electric power, consumed by entire industry.

In postwar years was considerably expanded the use/application of electric power for everyday and public-service needs. Widely was electrified urban transport, from year to year was expanded the electrification of rail transport and agriculture.

Power engineering of the USSR is characterized by the wide use of local fuels/propellants in hydroelectric energy. So, in 1955 it was manufactured electric power:

On hydroelectric power plants...14o/o

On thermo-electric powers station...86o/o

of them on the power plants, using:

coal..64o/o

peat...7o/o

petroleum fuel/propellant..9o/o

gas...4o/o

other energy resources...2o/o.

On thermal steam-turbine power plants in the same 1955 it was manufactured by 80o/o of entire electric power. In all at steam-turbine and hydraulic stations it was manufactured approximately/exemplarily by 94o/o of electric power. In the fraction/portion of power plants with other types of engines it was necessary a total of of approximately 6o/o of manufactured electric power. Hence it is apparent that the national economy of the USSR in essence is electrified from the steam-turbine and hydroelectric stations.

In 1957 on hydroelectric power plants was manufactured somewhat more than 39 billion kW•h, or approximately/exemplarily 19o/o of

entire electric power. The installed power of the hydroelectric power plants on 1 January, 1958, was approximately 10,000 MW (~20o/o).

In the year of the Soviet regime in our country are constructed hundreds of powerful/thick power plants [1-3]. The highest efficiency of district steam-turbine power plant in 1958 was 610 MW. The highest efficiency of the found in operation turbine units in 1958 was 150 MW at vapor pressure 170 atm(abs.) and temperature of overheating of vapor of 550°C. In 1958 Soviet plants mastered the production of the turbine units with a power of 200 MW. The first turbine unit of this power will be put into use in 1959. Industry is prepared for the production of the turbine units with a power of 220-300 MW and more.

Considerable development in the USSR underwent district heating. On the combined consumption/production/generation of thermal and electrical energy on the heat and power plants of the USSR occupies the first place in the world. In 1958 the centralized heat supply was realized in more than 230 cities even 100 settlements. The total power of central heating turbines on Soviet electric power plants in 1958 was approximately 13,500 MW, with about 36o/o of total power of thermal power plants. Wide district heating of industry and cities economizes to the national economy many million sink cool equivalent per annum.

The construction of hydroelectric power plants underwent development in the USSR only in the year of the Soviet regime. Is constructed many hydroelectric power plants: Volga im. V. I. Lenin with a power of 2300 MW, Gor'kiy - 400 MW and Rybinsk - 330 MW in Volga, Kama - 504 MW in Kama, Tsimlyanskiy - 166 MW on Don, Dneprovsk - 648 MW and Kakhovka - 312 MW in Dniepr, Mingechaurskiy - 356 MW on Kur, Gyumushkiy - 224 MW on Razdan, Irkutsk - 660 MW on Angara, etc.

The Volga hydroelectric power plant im. V. I. Lenin, equipped by 20 hydroaggregates in power on 115 MW, is most powerful/thick hydroelectric power plant in the world. In the USA the largest is Grand Coolie hydroelectric power plant on r. Columbine with a power of 1974 MW.

Great work is carried out also on the construction of transformer substations and electric systems of all voltages. For the characteristic of the volume of work on the construction of transformer substations it suffices to indicate that, according to the data of statistics, on 1 MW of the installed power of the aggregates/units of power plants it is necessary to install transformer substations to power to 4-5 MVA. For example, during the annual putting into commission on the power plants of the power of

5000 MW it is necessary to install transformer substations to enormous power - to 20,000-25,000 MVA.

The total length of electric systems only by voltage 35-400 kV in 1958 composed about 100,000 km. The ceiling voltage of aerial lines - 400 kV, cable - 110 kV. Electrical industry mastered the production of the oil-filled cables to voltages to 220 kV inclusively.

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Soviet industry in 1958 manufactured power transformers three-phase in power to 90 MVA inclusively, and single-phase - to 123.5 MVA. From the latter it is possible to complete three-phase groups in power to 370 MVA and by voltage to 400 kV. The highest efficiency of three-phase autotransformers - 180 MVA, and single-phase - 167 MVA from which it is possible to compose three-phase groups in power to 500 MVA.

On electrical stations and substations of the USSR continuously is introduced new, ever more advanced and economical equipment. So, at thermal power plants all more widely apply vapor of high pressure and high temperature of the overheating (see § 2-2). Are applied ever more powerful/thick aggregates/units and they install ever large/coarser power plants. In recent years powerful/thick

turbogenerators and synchronous condensers make predominantly with hydrogen cooling. Increasingly more widely is automated production process both in the part of the thermopower or water-power and in the part of electrical. As a result of accumulation and analysis of operating experience continuously is improved equipment maintenance, are introduced ever more advanced methods of its operation.

As a result of those indicated, and also series/row of other actions the average/mean specific consumption of cool equivalent per the manufactured kilowatt-nour of electric power on the thermal district power plants, which are the fundamental sources of power supply, was lowered from 576 g/kW•h in 1945 to 450 g/kW•h in 1957. On separate powerful/thick condensation power plants the specific fuel consumption in 1957 composed 420-400 g/kW•h and less. Decrease in the specific fuel consumptions per power plants gives to the country savings into several million tons of fuel/propellant per annum.

By the considerable achievement of Soviet power engineering was launching/starting in 1954 in the USSR the first in the world power plant in power 5000 kW on atomic energy. In 1958 is introduced in operation the first turn by the power of 100 MW of the second atomic power plant whose total power will be 600 MW. This is the large/coarsest in the world atomic power plant.

For the purpose of an increase in efficiency/cost-effectiveness and reliability of power supply and on the series/row of other reasons (for greater detail, see §3-4), all these years in different regions of the country was realized the wide association of power plants for a combined (parallel) work on the general/common/total electric systems of high voltage - they were created power systems. In the last two decades occurs the gradual association of adjacent power systems by the electric power lines of very high voltages and the creation of the large integrated systems by total power into several million kilowatts.

Even in the plan/layout of GOELRO, which personified brilliant ideas and electrifications of the socialist country, were outlined those main trends, in which thus already 40 years is developed Soviet power engineering and which briefly can be formulated as follows:

1. Electrification not of the separate chosen regions, but of the entire country, every possible development and reinforcement of economy and culture of union republics, the use of the richest raw and energy resources/lifetimes of the distant regions.

2. Systematic electrification of all branches of national economy, including agriculture, culture and mode of life.

3. Anticipating/leading rates developments of electrification; creation of reserve of electrical power.

4. Every possible use of local fuel/propellant by construction near places of yield of fuel/propellant of powerful/thick thermal power plants.

5. Wide construction of hydroelectric power plants.

6. Every possible development of district heating.

7. Systematic introduction of newest technology: vapor of high parameters, ever more powerful/thick and more ideal aggregates/units, automation of production processes, etc.

8. Composite solution of national-economic problems during construction of power plants, for example: with hydroelectric power plants - electric energy generation, improvement in navigation and in number of cases irrigation and irrigation of arid earth/ground; in thermal power plants - electrochemical use of fuel/propellant, i.e., obtaining from fuel/propellant of combustible gas and resins and use of fuel remainder for electric energy generation.

9. Association of power plants for multiple operation and

creation of power systems; gradual association of power systems and creation of power pool system of Soviet Union (YeES).

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1-3. Seven-year plan/layout of the electrification of the USSR.

The development of Soviet power engineering to the next 7 years is determined by the check digits of the development of the national economy of the USSR during the years 1959-1965, affirmed by XXI Congress of KPSS [КПСС - CPSU].

Primary task of seven-year plan/layout are "further powerful/thick lift of all branches of the economy on the basis of a preferred increase in the heavy industry, considerable amplification of the economic potential of the country in order to ensure a continuous rise the standard of living of people.

As a result of the fulfillment of this plan will made the decisive step/pitch in the creation of the material and technical basis of communism and in the accomplishment of the fundamental economic problem of the USSR - within historically shortest periods overtake and outdistance the most developed capitalist countries in production per capita of population" [1].

FOOTNOTE [1]. The check digits of the development of the national economy of the USSR during the years 1959-1965, "Pravda", No 39 of 3 February, 1959. ENDFOOTNOTE.

The gross output of industry in 1965 in comparison with 1958 grows/rises approximately/exemplarily to 80o/o, including production of the means of production - approximately/exemplarily to 85-88o/o, and the production of consumer goods - approximately/exemplarily to 62-65o/o.

For the purpose of every possible acceleration of the economic development of the country and maximum gain in time in peaceful economic competition with the capitalist countries seven-year plan/layout provides for a preferred increase in those branches of the heavy industry which to the greatest degree contribute to further rapid lift of national economy. For the development of power engineering important value has the provided by plan/layout change in the structure of heat balance by the priority development of yield and production of the most economical forms of fuel/propellant - oil and gas. The share of oil and gas in the total volume of the production of fuel/propellant will increase from 31o/o in 1958 to 51o/o in 1965, while the share of carbon/coal respectively will be

lowered from 59 to 43o/o. This will make it possible in the current seventh anniversary to considerably expand the use/application of natural gas and petroleum residue as power house fuel on power plants, which will give the series/row of the economic advantages: the decrease of the periods of construction and initial costs of power plants, decrease of the number of operating personnel, reduction in the prime cost of electric power, etc., about which it is in more detail stated in § 2-2.

In accordance with the established/installed increase in the industrial production is designed the development of power engineering of the country. During a seven-year period the annual output of electric power by all power plants of the USSR must increase approximately/exemplarily 2.2 times and in 1965 be 500-520 billion kW•h (approximately/exemplarily 2260 kW•h to man per annum). The installed power of all power plants for seventh anniversary grows/rises more than 2 times. On turbine power plants will be only introduced the new power of 58,000-60,000 MW, that will exceed the total power of all power plants of the USSR into 1958 the yearly putting into commission of new power on power plants it will achieve the enormous value: 8000-11,000 MW.

So considerable an increase in the power of power plants can be achieved/reached only on the basis of the preferred construction of

the large/coarse thermal power plants, which work on cheap carbon/coals, natural gas and petroleum residue. Should be noted the impossibility of achieving the same results on the basis of the preferred construction of hydroelectric power plants as a result of the fact that the periods of construction and expenditure for the construction of hydroelectric power plants are considerably more than the thermal power plants of the same power (see § 2-3).

Based on this, seven-year plan/layout it provides that a fundamental gain of power plants in the size/dimension of 47,000-50,000 MW will be achieved/reached mainly due to the construction of large/coarse district condensation steam-turbine power plants in power on 1000 MW and more, the equipped by a comparatively small number turbine units in power 100, 150, 200 and 300 MW with the high steam parameters and carried out on the simplest block thermal circuit (boiler - turbine, see § 2-2). At the construction of large/coarse power plants are achieved the considerable decrease of the periods of construction, of capital expenditures and number of personnel, the decrease of the prime cost of electric power (see § 2-2).

In different regions of the country have already been installed la· .e/coarse district power plants in power on 1000 MW and more: Tom'-Usinskaya, Nazarovskaya, Belovskaya, etc. with turbine units

100, 150 and 200 MW. The first turbine units with a power of 200 MW will be put into use during the years 1959-1960. During the years 1960-1962 will be manufactured the turbine units with a power of 220-300 MW.

Is projected/designed the construction of thermal power plants in power to 1800-2400 MW with turbine units in power on 300-600 MW with the parameters of vapor to 300 atm(abs.) and 650°C at boiler units by evaporation capacity to 1500-1800 t/hs.

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For a comparison let us point out that in the USA the power of separate thermal power plants reaches 1000-1500 MW in turbine units in power to 250 MW, boiler units by evaporation capacity to 780 t/hs and parameters of vapor to 300 atm(abs.) and 620°C.

During the years 1959-1965 in operation they must be introduced to the hydroelectric power plant: Stalingrad with a power of 2530 MW (22 hydraulic generators on 115 MW) in Volga, fraternal with a power of 4500 MW (20 hydraulic generators on 225 MW) on Angara, Votkinskiy - 1000 MW in Kama, Kremenchug -625 MW in Dniepr, Bukhtarmin - 525 MW on the Irtysh and some others.

In the year of seven year school will be also expanded/scanned the construction of the series/row of large/coarse thermal and hydraulic power plants with their introduction/input into operation after 1965. From planned during this period hydroelectric power plants of the largest will be Krasnoyarsk on the Yenisei with a power of 5000 MW, at which will be established/installed the hydroaggregates in power on 500 MW.

For a seven-year period it is provided to place in operation the series/row of powerful/thick atomic power plants with different types of reactors.

Together with powerful/thick power plants if necessary will be installed the power plants of comparatively low power. So, for heat- and power supply of cities and industrial enterprises is provided the construction of heat and power plants with central heating turbine units with a power of to 25-50, but subsequently and 100 MW.

In regions, not included by the electric systems of power systems, will be installed also low-power power plants for the power supply of small users, mainly agricultural. Seven-year plan/layout provided the construction of inter-kolkhoz and inter-district power plants with the enlistment of the means of kolkhozes.

The extent of electrical networks by voltage 35-500 kV for seventh anniversary will increase approximately/exemplarily 2.5-3 times and will achieve value on the order of 250-300 thousand km. Is in prospect the construction of an enormous number of transformer substations of all possible power and all voltages to 500 kV inclusively.

Together with further electrification of industry seven-year plan/layout provides for a considerable improvement in the electro- and heat supply of cities and electrification of all state farms, repair- technical stations, kolkhozes and workers it is settlement. Will be electrified approximately/exemplarily 20 thousand km of railroads. As a result of the fulfillment of seven-year plan to a considerable degree will be realized the idea. V. I. Lenin about the continuous electrification of the country.

As in the year of the previous five-year plans, must be provided continuous raising the technical level of electrical stations and networks/grids, creation and use/application of ever more advanced aggregates/units, thermal, hydraulic engineering and electrical equipment, more advanced constructive solutions, etc.

Before machine-building and electrical engineering industries is posed the problem of full of the guarantee new energy construction

with entire necessary equipment. Transformer plants within the next few years must create single-phases transformer and autotransformers in power to 300 MVA inclusively for staffing of groups in power to 900 MVA and three-phase transformers and autotransformers in power to 360-450 MVA to all voltages to 500 kV inclusively [1-4].

The most important conditions of fulfilling the program of energy construction are every possible improvement in the quality of construction ones and are assembling works, reduction in the cost/value and shortening the periods of construction. For this is necessary the introduction of the industrial methods of construction, the wide application of composite constructions/designs, including the precast reinforced concrete, rational simplification in the thermal and electrical diagrams and layouts of power and electrical equipment, etc. It is very important to attain sharp acceleration and reduction of prices of the construction of thermal and electrical networks, electric power lines of nigh voltages, transformer substations.

Are such the large problems, which into the next 7 years must be solved by Soviet power engineers.

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Chapter Two.

BRIEF INFORMATION ABOUT EQUIPMENT AND OPERATION OF ELECTRICAL STATIONS.

2-1. General information.

Electric power is developed in special enterprises - the power plants, which convert into electric power other forms of the energy: chemical energy of fuel/propellant, hydraulic power, energy of the wind, atomic energy, etc. Manufactured by station electric power is transmitted by the air or cable lines of electric systems to different users: industrial, communal, agricultural, everyday ones, etc.

Types of power plants. Depending on the utilized form of energy distinguish power plants thermal, hydroelectric, atomic, wind, etc.

On thermal power plants is utilized solid, liquid and gaseous

fuel. Depending on the kind of primary motor/engine, which revolves electric generator, thermal power plants they are subdivided into station with steam turbines, steam engines (engines), internal combustion engines and gas rubies.

Stations with steam turbines, furthermore, they are subdivided into condensation ones and central heating ones.

The electrification of the USSR, as noted in §1-2, is realized in essence from thermal steam-turbine power plants and hydroelectric stations. Within the next few years considerable development will undergo, apparently, also the atomic power plants.

According to the character of the users of electric power and by region of the maintenance/servicing power plant it is possible to subdivide into: urban (public-service), industrial ones (factory and plant), agricultural ones, district, special designation/purpose (railroad, etc.). This subdivision is somewhat conditional for the power plants, which work to the general/common/total network/grid of the power system (see §3-4). For example, the connected with the electric system of power system urban power plant, besides the nourishment of the users of city, usually puts out the part of developed by it electric power into the electric system of the system where it is utilized for the nourishment of industrial, agricultural

and other users. Then it is possible to speak also about other stations, connected with the network/grid of system. Therefore, relating station to one of the groups indicated, bear in mind preferred character its loads.

The mode of operation of power plants is very peculiar and essentially it differs from the mode/conditions of work of any industrial enterprise. The power plant, connected with electric consumers with electrical network (see §3-2, Fig. 3-5), can develop at each moment of time only this quantity of electric power, what at this moment of time consume all connected to its network/grid electrical receivers. There cannot be the productions of electric power without its simultaneous consumption; therefore the load of power plant is determined by the power, simultaneously consumed by all connected to its network/grid electrical receivers.

Each user has the specific operating mode, with respect to what changes his electrical load. The inconstancy of the use mode of electric power leads also to the varying load of electric energy generation - the load of the generators of power plant changes in accordance with a change in the load of its users. Variable/alternating is also the load of all intermediate components/links of the transmission system and electrical power distribution: the electric power lines, substations, etc.

A change in the loads of power plants as any other electrical devices, is convenient to depict graphically in the form of the graphs/curves of the loads which are constructed in the rectangular coordinate axes, plotting/depositing along the axis of the ordinates of load, and along the axis of abscissas - the time, during which they are examined changes in loads. They most frequently use the diurnal graphs/curves of loads. One of similar graphs/curves of station is given in Fig. 2-1.

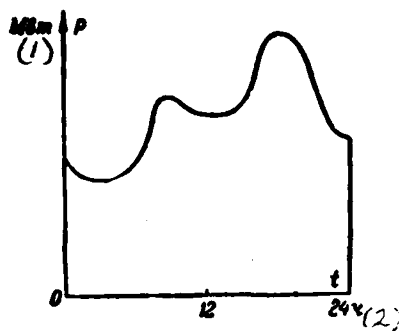

Fig. 2-1. Diurnal graph/curve of the load of power plant.

Key: (1). MW. (2). h.

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The form of diurnal graph/curve depends on composition and mode of operation of the receivers of electric power (for greater detail, see chapter 4).

2-2. Thermal power plants.

Steam-turbine condensation power plants work on solid, liquid or gaseous fuel. Most widely is utilized the solid fuel: carbon/coals of different deposits, especially brown coal, coal fines, anthracite fines and withdrawals/departures of the enrichment of carbon/coals (semi-finished product), bituminous shale, cake and milling peat,

etc. On the use of local solid fuels for the electric energy generation of the USSR occupies the first place in the world.

Solid fuel they burn in the furnaces of boilers in cake view of gratings (layer combustion) or in dustlike state (chamber combustion). The best ignition method of local low-calorie fuels/propellants with high ash contents and moisture is combustion in dustlike state.

The layer combustion of solid fuel applies comparatively little and usually with the boilers of small evaporation capacity and to the low parameters of steam.

As gas fuel/propellant utilize a natural gas, and at the stations of metallurgical plants - also domain and coke gases. In certain cases the gas utilizes as a supplementary fuel/propellant to solid or liquid, which is fundamental.

The use/application of a natural gas on power plants economically is very effective: approximately/exemplarily to 20o/o decrease initial costs of station due to sharp simplification and reduction of prices of the fuel economy of station and several times decreases the prime cost of electric power as a result of considerably smaller expenditures on fuel/propellant, decreases of

the number of personnel and decrease in the depreciation allowance.

Because of the absence of bulky carbon storages, coal feeds, ash removal and ash collection, crushing and mill devices/equipment, necessary during the combustion of carbon/coal, not only decrease initial costs of stations on gas, but also substantially are reduced the periods of their installation - on the average on 8-10 mo., which considerably accelerates the putting into commission of new power.

The efficiency of boiler units on gas is raised by 4-5o/o due to the absence of the heat losses as a result of mechanical incomplete burning and decrease in the heat losses with stack gases.

The number of service personnel is reduced not only due to simplification in the fuel economy, but also as a result of the possibility of the wider automation of boiler units which during the combustion of gas is realized considerably simpler and it is cheaper, rather than during the combustion of carbon/coal.

Prime cost of the natural gas considerably lower than prime cost of carbon/coal. For example, with translation on 1 t of cool equivalent it proves to be that the prime cost of natural gas is 15-20 times less than the prime cost of donets carbon/coal. Transport with the aid of the gas pipes 1 t of conditional gas fuel/propellant

is approximately/exemplarily 8 times cheaper than 1 t of carbon/coal.

With gas fuel/propellant considerably is reduced the expenditure of electric power for its own needs of station.

Taking into account advantages indicated above of gas as power house fuel, and also the provided by seven-year plan/layout increase in the yield of natural gas, is planned into 1959-1965 to sharply increase the use of a natural gas for electric energy generation. While in 1957 on the power plants, gas-fired, were manufactured less than 16 billion kW•h (approximately/exemplarily 7.5o/o of entire consumption/production/generation), then into 1965 electric energy generation at such stations it must increase not less than 5 times and be approximately/exemplarily 80-90 billion kW•h (15-18o/o of entire consumption/production/generation).

The use of gas on urban and industrial heat and power plants considerably improves sanitary-hygienic conditions, since is removed the contamination of the territories of cities and enterprises by escapes with flue gases.

In 1959-1965 is projected/designed the installation of the number of the heat and power plants, equipped by gas turbines. At present Soviet plants manufacture gas turbines in power to 25 MW and

they project/design with the power of 50 MW.

In connection with the outlined for seventh anniversary 1959-1965 the increase of the yearly yield of oil to 230-240 mln. shows the possibility of using extensively as fuel/propellant for power plants also petroleum residue, which gives approximately/exemplarily the same order of the advantage as the use of a natural gas. First of all to petroleum residue it is expedient to transfer all heat and power plants in oil refineries, and also power plants, arranged/located in immediate proximity of them. Is possible installation on petroleum residue also of powerful/thick district power plants.

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Gas and petroleum residue are introduced into the furnaces of the boilers through burners (injector) and are burned in the form of flame.

Fig. 2-2 gives the simplified flow chart of the simplest steam-turbine power plant. From the storage of fuel/propellant 1 with the aid of conveyer (usually strip/tape) cake carbon/coal U enters carbon bunker 2, arranged/located in boiler room before boiler 4. From bunker carbon/coal falls to the chain grate of furnace 3, where

it burns. The separating in furnace heat through the surfaces of heating boiler is transmitted to the found in it water and generated in it steam.

Gases G from furnace and boiler flues are exhausted by exhaust fan 5 and through the chimney stack are rejected in the atmosphere.

From the boiler overheated steam PP on steam pipe enters steam turbine 6 and it gives it in rotation. Turbine revolves generator 7 whose shaft is connected by clutch with the shaft of turbine. Manufactured in generator electric power EE enters the collecting mains SSh of generator voltage also from them - into electric system along the waste/exiting lines.

In turbine the steam passes a series/row of steps/stages, completing the mechanical work; in this case pressure and its enthalpy gradually they decrease. The work, completed by steam in turbine, depends from pressure difference in steam that comes the turbine and emerging from the turbine. The greater this pressure difference, the large part of thermal energy of steam is converted into mechanical energy in turbine. At certain pressure of steam, that enters the turbine, pressure difference the greater, the less the pressure of steam that emerges from turbine, i.e., the less the pressure of steam in capacitor/condenser 8. For more

full/totaler/more complete use of thermal energy of steam to more advantageously support in turbine condenser subatmospheric pressure.

The stagnation pressure of the exhaust steam in contemporary turbines is usually 0.04-0.03 atm(abs.), which is achieved by creation and permanent maintenance in the capacitor/condenser of 8 turbines of the corresponding rarefaction/evacuation (vacuum). For this, first of all, necessary that the generated steam of OP, which continuously enters the capacitor/condenser of 8 turbines, intensely would be cooled rapidly it would be condensed. Is reached this via passage in a proper quantity through the tubes of the capacitor/condenser of cold circulation water TsV, which supplies circulating pump 9 of any basin - river, pond, lake. Depending on the temperature of circulation water (by winter, summer, etc.) a quantity of it must be 50-80 times ot more than a quantity of coming the exhaust-steam condenser.

In the case of absence near the station of the adequate/approaching basin is utilized one and the same space of circulation water, but artificially cooling it in any special installations, for example tower-coolant (saltpan).

The air, which penetrates into capacitor/condenser together with the exhaust steam and through leakages/loosenesses, is driven out by

special steam-jet apparatus - ejector 10.

Forming in capacitor/condenser 8 condensate K is evacuated by condensate pump 11 into supply tank 12. From the latter the feed water PV by feed pump 13 is supplied into boiler 4. Thus, in steam-turbine installation of feed water, vapor and condensate are turned on closed cycle, thanks to which is provided the small contamination of boiler.

The entering the exhaust-steam condenser even at stagnation pressure 0.04-0.03 atm (abs.), contains an an even more considerable quantity of unused heat whose large part is absorbed by circulation water and is taken away by it into basin, i.e., it is lost unproductively.

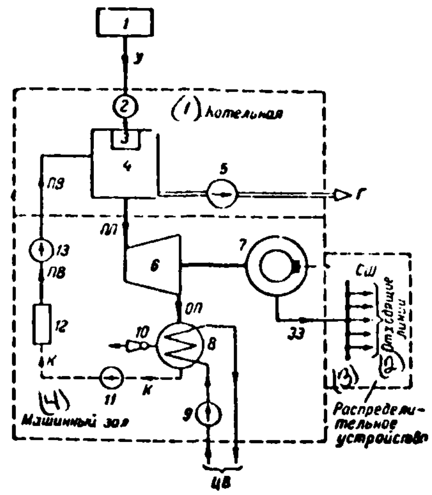

Fig. 2-2. Simplified fundamental flow chart of steam-turbine condensation power plant.

Key: (1). Boiler room. (2). Waste/exiting lines. (3). Distributor. (4). Machine room.

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Let us take in the form of an example the case when into turbine it enters steam with initial pressure 90 atm(abs.) with temperature of 500°C and enthalpy 816 kcal/kg. At the stagnation pressure of the generated steam 0.04 atm(abs.) its enthalpy are approximately 525 kcal/kg. From this quantity of heat only very small part, approximately/exemplarily 25-28 kcal/kg, returns with condensate to

the feed system of boiler. Nevertheless remaining heat, approximately/exemplarily 525-25=500 kcal/kg, or (500/816) 100=61o/o, is lost unproductive with circulation water. As a result of a large quantity of circulation water its temperature is small; therefore its use for any purposes is virtually impossible.

The specific heat losses occur also in boiler units, steam pipes, turbines, generators and other elements/cells of power plant.

Because of this entire efficiency of the power plants, carried out on diagram in Fig. 2-2, usually it is comparatively small and does not exceed 16-18o/o.

An increase in the efficieucy of condensation power plants is achieved by the path:

1) the use/application of dustlike (chamber) combustion of the solid fuel;

2) preheating feed water with the use of heat of steam, the partially mastered in turbine (the so-called regenerative preheating of feed water), and also heat of the waste/exiting flue gases;

3) preheating the entering the furnace boiler of air with the

use of heat of the waste/exiting flue gases;

4) increase in the power of aggregates/units, since powerful/thick aggregates/units have the larger efficiency;

5) increase in the parameters of steam.

Fig. 2-3 gives the fundamental flow chart of steam-turbine condensation power plant with the regenerative preheating of feed water, using waste heat and by worker on the coal dust. From storage 1 cake carbon/coal UK enters coal-crushing device/equipment 2, where it passes through the crushers, which divide/mark off it into small/fine pieces. If station works on the anthracite fines, then crushing device/equipment does not install and tail from storage 1 they transport directly into boiler.

Crushed carbon/coal UD enters the carbon bunker of 3 of dust peparing devices/equipment which normally is placed in boiler room. From bunker 3 carbon/coal falls into carbon mill 4, which grinds it to dustlike state. From mill the coal dust UP either enters the arranged/located on boiler bunker 5 of finished coal dust (system of pulv ized coal preparation with intermediate pulverized coal bunker), or directly through pulverized coal burners 7 it is injected into the furnace of 8 boilers (system of pulverized coal preparation

without intermediate pulverized coal bunker).

From bunker 5 the coal dust UP is supplied by the feeders of dust 6 and through burners 7 is injected into the furnace of boiler 9 by hot air VG, which is supplied by blast fan 13. The feeders of bullet 6, that have electric-motor drive, make it possible to change a quantity of carbon dust, which enters the furnace of boiler with its work with different evaporation capacity.

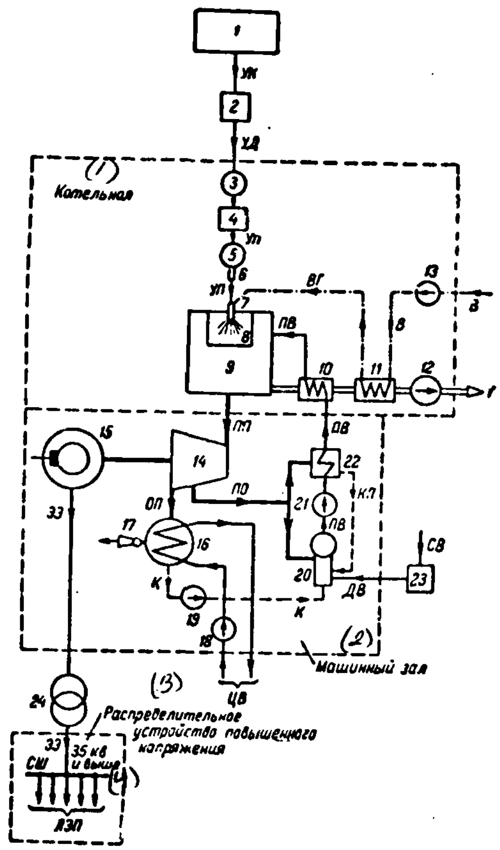

Fig. 2-3. Fundamental flow chart of steam-turbine condensation power plant, that works on the coal dust.

Key: (1). Boiler room. (2). Machine room. (3). Distributor of increased voltage. (4). 35 kV into above.

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Hot air VG, necessary for the combustion of carbon bullet, preliminarily passes through air heater 11, where it is preheated by the waste/exiting flue gases G, which are exhausted from boiler flues by exhaust fan 12. Cold air V takes away/gathers outside. Preheating air decreases the heat losses with waste gas and improves the process of the combustion of the coal dust. In the furnace of boiler the coal dust burns in suspension, forming flame in the form of flame with very high temperature. Is provided a good combustion of any fuel/propellant.

From boiler 9 into steam turbine 14 enters overheated steam PP. Certain quantity of that partially generated in turbine of steam PO (steam of selection) is abstracted/removed from the intermediate steps/stages of turbine for preheating feed water. Remaining steam passes through the subsequent steps/stages of turbine. Completely mastered in the turbine of steam OP enters capacitor/condenser 16, where it is condensed by circulation water TsV, supplied with circulating pump 18. The necessary rarefaction/evacuation in capacitor/condenser supports steam ejector 17.

From turbine condenser the condensate K is pumped over by condensate pump 19 into deaerator 20.

Deaerator serves for distance from feed water of the dissolved

in it gases, especially atmospheric oxygen, since it causes intense corrosion and rapid decomposition of the heating pipes of boiler, tubes of water heaters and feed conduits/manifolds. In feedwater deaerator is preheated by steam PO from intermediate selection before the temperature, with which occurs the intense isolation/liberation of the dissolved in it gases.

From feedwater deaerator PV is evacuated by feed pump 21. On path into boiler the feed water PV passes through several water heaters (in the diagram is shown one water heater - 22), in which the water is preheated by steam from the intermediate selections of turbine. The entering in water heaters steam is condensed; condensate KP is abstracted/removed into deaerator.

Condensation steam turbines have several intermediate selections for preheating feed water. The regenerative preheating of feed water by steam from the intermediate selections of turbine significantly raises the efficiency of power plant. Is explained this by the fact that selection from the intermediate steps/stages of the turbine of the partially exhaust steam decreases a quantity of steam that enters turbine condenser, and consequently, as this escape/ensues of that presented above, and the heat loss with circulation water. The heat, which is contained in a pair of selection, returns with feed water to boiler aggregate/unit.

Additionally feed water is preheated in the feed-water economizer of 10 boilers with the use of heat of the waste/exiting flue gases. Depending on pressure of steam in boiler the temperature of feed water upon the input into boiler composes 160-260°C. The feed of boilers by the heated water improves their work and raises their efficiency/cost-effectiveness.

On power plants occur some losses of steam and condensate as a result of the boil-offs and condensate in the system of equipment and conduits/manifolds of station, certain expenditure of steam for technical needs (blowout of boilers, heating of petroleum residue, etc.), and also losses of steam and condensate with start and stop of equipment - boilers, turbines, etc. (to warm-up and purging of the elements/cells of boiler and steam pipes, the warm-up of turbines, etc.). For the completion/replenishment of these losses certain quantity of damp/crude water SV is chemically cleaned in special installation 23, whence supplementary water DV enters deaerator 20.

The efficiency of power plant increases during the use/application of aggregates/units of large power (boiler units and turbine units), since powerful/thick aggregates/units are more economical than small/fine.

Great effect on the efficiency of power plant have the parameters of steam: with an increase in the initial pressure and temperature of overheating of steam the efficiency of station increases. For an example let us point out that the efficiency of condensation power plants on pulverized coal fuel/propellant have the approximately/exemplarily following values: in the average parameters of steam 29-35 atm(abs.) and 400-435°C turbine units in power to 50 MW to 25-28o/o; in the high parameters of steam 90 atm(abs.) and 500°C and the turbine units with a power of 50-100 MW to 30-32o/o; in the superhigh parameters of steam 170-220 atm(abs.) and 550-650°C the turbine units with a power of 100-300 MW to 34-40o/o.

An increase in the efficiency of power plant leads to the decrease of the specific consumption of fuel (g/kW•h) or heat (kcal/kW•h) to manufactured electric power, and consequently, to the reduction of prices of electric power.

Thus, as a result of introduction everything of the more advanced equipment the efficiency of power plants grows/rises.

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In spite of this, nevertheless it is necessary to note that even on the very powerful/thick condensation power plants of the high and ultrahigh pressures only by 30-40o/o of energy of fuel/propellant it is utilized productively, i.e., it is converted into electric power. The others 70-60o/o energy of fuel/propellant are lost unproductive in the process of the production of electric power.

From the aforesaid it is possible to draw the conclusion that the installation of condensation power plants on long-range fuel/propellant is economically inexpedient. On the dismantled/selected diagram at the USSR work and are installed mainly district power plants on local fuel/propellant, since electric transmission up to great distances to the places of its consumption proves to be economically more advantageous, than transport along the railroads of the low-calorie local fuel/propellant, which contains a large quantity of ash and moisture.

Since district power plants usually are considerably distant from the users of electric power, then developed by them electric power is distributed by means of high-voltage electric power lines by voltage 35 kV and it is above, that encompass the considerable regions of field service - in a radius of several tens and even hundreds of kilometers. In accordance with this in the diagram in Fig. 2-3 it is shown that from generator 15 electric power 33 enter

step-up transformer 24, and then the collecting mains SSh by voltage 35 kV and it is above, from which will move away the electric power lines LEP, which feed high-voltage district electric system.

In Fig. 2-2 and 2-3 dotted lines limited the outlines of boiler room, machine room and electrical distributor. The latter serves for the reception/procedure of electric power, manufactured by the generators of station, and its distribution according to the waste/exiting electric power lines.

In distributor are placed the disconnecting, shielding and measuring electrical apparatuses, coupling busbars and auxilople.

At station there is also a control board, whence attendant personnel exercises control and control over the work of electrical equipment of installation.

It should be noted that the installation of large/coarse district power plants with the powerful/thick aggregates/units of high and ultrahigh pressures is profitable not only as a result of the decrease of the specific consumption of fuel and increase in the efficiency of stations, as this was discussed above, but also as a result of a sharp decrease in initial initial costs of power plants and decrease of the number of personnel, which also leads to the

decrease of the cost/value of electric power.

For example, according to the data of Electroheat-plan initial initial costs of the power plant with a power of 1200 MW into aggregates/units on 200 MW approximately/exemplarily to 26-30o/o less than initial costs of three power plants on 400 MW with aggregates/units on 100 MW (to the same total power of 1200 MW). At the same time the number of personnel decreases in one station approximately/exemplarily 2-3 times.

The profitability of the installation of very large/coarse power plants illustrate also some technical-economic indices, given in Table 2-1.

Thermal district power plants at present normally are installed on the so-called block thermal circuit in which on each turbine unit installs one boiler, moreover both on feed water and on steam the boilers of different turbine units do not connect (are absent the cross connections between blocks). As an exception in the absence of large/coarse boilers are installed two boilers to one turbine unit.

The use/application of block diagrams proved to be possible as a result of the high reliability of the operation of contemporary boiler units.

Table 2-1. Some technical-economic indices of large/coarse thermal district power plants.

(a) Показатели	(b) Электростанция мощностью		
	600 (c) Мвт	1 200 (c) Мвт	2 400 (c) Мвт
1. Число турбоагрегатов	6	6	4
2. Мощность турбоагрегата, Мвт	100	200	600
3. Стоимость 1 квт установленной мощности (в ценах 1955 г.), руб.	1 075	850	630
4. Удельный расход условного топлива на выработанный киловатт-час, г	410—400	332—324	300
5. Коэффициент полезного действия станции, %	30—30,7	37—38	41
6. Расход электроэнергии на собственные нужды, %	7,5—7,8	6,5—7	6,4
7. Штатный коэффициент, чел/Мвт	1,7—2	0,5—0,6	0,35—0,45
8. Удельный объем главного корпуса, $м^3/квт$	1,15	0,6	0,36

Key: (a). Indices. (b). Power plant by power. (c). MW. (1). Number of turbine units. (2). Power of turbine unit, MW. (3). Cost/value of 1 kW of installed power (in values 1955), rub. (4). Specific expenditure of cool equivalent for manufactured kilowatt-hour, g. (5). Efficiency of station, o/o. (6). Expenditure of electric power for its own needs, o/o. (7). Regular coefficient, man/MW. (8). Specific volume of main housing, m^3/kW.

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The major advantages of the block stations:

1) is facilitated use/application the steam of the high and superhigh parameters as a result of the simpler system of the steam pipes;

2) are simplified and becomes clearer the flow chart of station, in consequence of which increases the reliability of operation and is facilitated the operation;

3) decrease, and sometimes can generally be absent the stand-by auxiliary thermo-mechanical equipment;

4) is reduced the volume of the construction and installation works;

5) decrease fundamental initial costs of the station;

6) is provided the convenient expansion of station by blocks, the new blocks if necessary can have higher parameters of steam.

If station is made from blocks with one boiler, then in comparison with the station, carried out on the nonmodular diagram, the specific volume of building decreases approximately/exemplarily

to 20o/o, substantially decrease the length of conduits/manifolds and a quantity of reinforcement on them, a number of measuring meters, considerably is simplified thermal automation.

For control of thermo-mechanical equipment install block panels (22 in Fig. 2-4), usually one to two blocks, the available in main housing stations. With block panels and wide automation of thermo-mechanical equipment it proves to be excessive to have attendant personnel directly in fundamental and auxiliary thermomechanical equipment.

Fig. 2-4 in the form of an example gives the schematic cross section of the main housing of powerful/thick thermal power plant with turboassemblies with a power of 150 MW. On the designation/purpose of the basic equipment, shown in this section/cut, it was said earlier. Let us additionally note that feeder 3 serves for controlling the admission of raw carbon/coal from bunker 2 into mill 4.

The mixture of the coal dust and air from mill enters separator 5, and then into cyclone 6. In separator from coal-air mixture are separate/liberated the large/coarse unground particles of carbon/coal, absorbed by airflow, which from separator are headed back into mill. In cyclone the coal dust is separate/liberated from

air and then along tube it is headed for pulverized coal bunker 7 (it is arranged/located after raw coal bunker 2). The supply to carbon of dust to the pulverized coal burners of boiler and burners themselves Fig. 2-4 does not show. Also is not shown fan, suction air from cyclone 6 and feeding it to the burners of boiler.

After feed-water economizer 9 and air heater 10 flue gases fall into wet ash catcher (scrubber) 11, where the gas is cleaned of the weighed in it ash. The purified gas is exhausted by exhaust fan 12 and on duct is headed for chimney stack 13. One should say that during the dustlike combustion of fuel/propellant the large part of the ash will be carried by flue gases from boiler aggregate/unit.

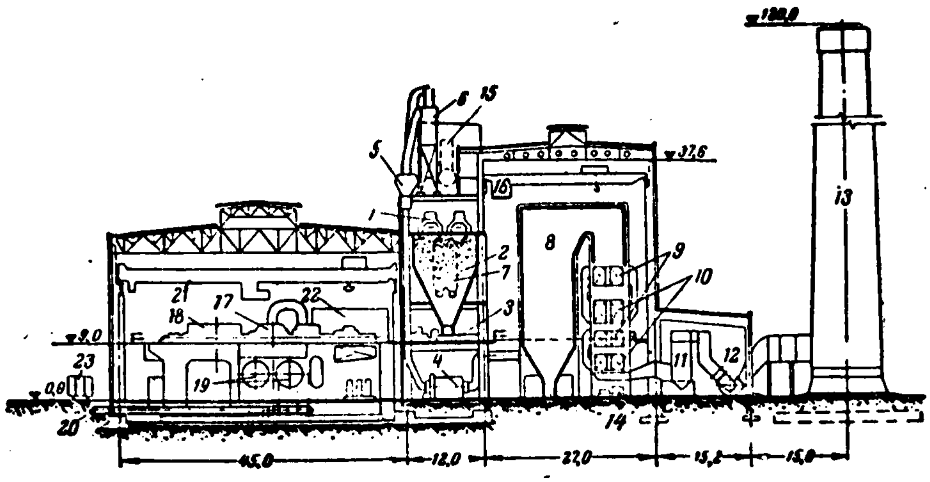

Fig. 2-4. Schematic cross section of the main housing of powerful/thick thermal district power plant. 1 - carbon conveyer; 2 - raw coal bunker; 3 - feed of damp/crude carbon/coal; 4 - carbon mill; 5 - separator; 6 - cyclone; 7 - bunker of the coal dust; 8 - steam boiler; 9 - two steps/stages of the feed-water economizer; 10 - two steps/stages of the air heater; 11 - wet ash catcher (scrubber); 12 - exhaust fan; 13 - chimney stack; 14 - blast fan; 15 - deaerator; 16 - bridge crane of the boiler room; 17 - steam turbine; 18 - turbogenerator; 19 - turbine condenser; 20 - pipelines of the circulation water; 21 - bridge crane of the machine room; 22 - control board of block boiler-turbine; 23 - transformer for the feed of their own needs.

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Therefore in the absence of gas cleaning inadmissibly is soiled air in the adjacent to power plant region. For scrubbing of gas are applied the ash catchers of different systems, including electric filters.

Fig. 2-5 shows the general layout of the fundamental installations of powerful/thick thermal district power plant, at which it is not difficult to be dismantled/selected, being guided by that presented above and by the elucidating text under figure.

Steam-turbine central heating power plants (heat and power plant) are intended for the supply the users with not only electrical, but also thermal energy. For the transmission from such stations of thermal energy as heat-transfer agent apply depending on the type of user steam or hot water. The place of the installation of heat and power plants is determined by the conditions of the transport of thermal energy.

Fig. 2-6 gives the fundamental thermal circuit of heat and power plant in that its part in which it differs from the diagram of condensation power plant by Fig. 2-3 (is accepted the same numbering of elements/cells).

The entering the turbine overheated steam PP (Fig. 2-6) passes the part of the steps/stages of turbine and, being expanded, it completes the mechanical work; in this case its pressure and enthalpy they decrease. Then certain quantity of steam PO is abstracted/removed from the intermediate steps/stages of turbine for district heating and the regenerative preheating of feed water. Remainder/residue of steam passes the remaining steps/stages of turbine and it is expanded to final condenser backpressure, completing in this case mechanical work.

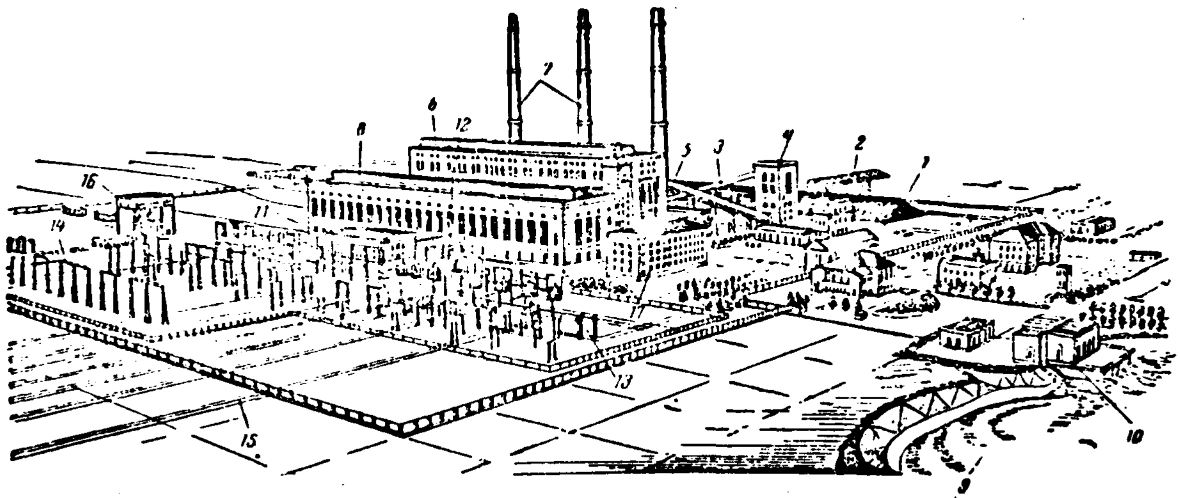

Fig. 2-5. Fundamental installations of powerful/thick thermal district power plant. 1 - pile of carbon/coal; 2 - bridge grab carbon tap/crane; 3 - closed pier of belt conveyors from storage into the coal breakers; 4 - coal-crushing location; 5 - closed pier of belt conveyors from coal breakers into the bunker location of the boiler room; 6 - boiler room; 7 - the chimney stacks; 8 - machine room; 9 - reservoir; 10 - coast pumping; 11 - building of control board; 12 - transient bridge; 13 - open distributor 110 kg; 14 - the same 220 kV; 15 - waste/exiting electric power lines 110 kV; 16 - transformer workshop; 17 - official housing.

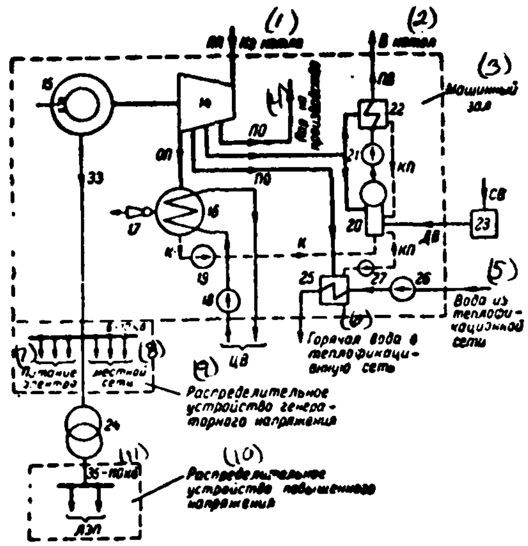

Fig. 2-6. Fundamental thermal circuit of heat and power plant.

Key: (1). From boiler. (2). In boiler. (3). Machine room. (4). Steam for production. (5). Water from central heating network/grid. (6). Hot water into central heating network/grid. (7). Power supply. (8). Local network/grid. (9). Distributor of generator voltage. (10). Distributor of increased voltage. (11). kV.

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Steam from central heating selections it enters directly the production or into water heater (boiler) 25, through which by supply-line pump 26 drives away itself the water, utilized for the

heating of buildings and other needs of municipal services and industrial enterprises. Condensate KP from water heater is pumped over by pump 27 into deaerator.

I- steaming is supplied when near station are industrial enterprises, which require steam for their technological process.

A quantity of selected/taken from intermediate steps/stages of turbine steam is determined by the requirement of thermal users for hot water and steam.

Use for district heating of the partially exhaust steam from the intermediate steps/stages of turbine decreases a quantity of steam that enters its capacitor/condenser and, consequently, also the loss of heat with circulation water. Entire heat, which is contained in hot water and steam which enter from station into central heating network/grid, is considered the usefully tempered heat.

The overall efficiency of heat and power plants, the considering tempering to users of both forms of energy - electrical and thermal, reach 60-70o/o and even it is more. This efficiency characterizes the overall use of energy of fuel/propellant on heat and power plants. It is obvious that the efficiency/cost-effectiveness of the work of heat and power plant depends on the value of selection of steam for

thermalization. With the decrease of a quantity of steam that enters the capacitors/condensers of central heating of turbine, efficiency of heat and power plant grows/rises.

In the case of full of the absence heat distribution into central heating network/grid the turbines work in the condensation mode/conditions; with this efficiency of station usually do not exceed 28-32o/o.

From the aforesaid it follows that the most economical mode/conditions of the work of heat and power plant is its work on the graph/curve of thermal consumption, i.e., with the control of admission of steam into turbines with respect to its selection to district heating with minimum passage of steam into capacitor/condenser. A smallest possible quantity of steam that passes the latter/last steps/stages of turbine and entering the capacitor/condenser, it is indicated by the manufacturing plant of turbine from the considerations of the work of its latter/last steps/stages.

Since the modes/conditions of the work of thermal and electrical users are different, the realization of the mode/conditions of the work of heat and power plant indicated is possible only with of its to multiple operation with other power stations of power system -

thermal and hydroelectric.

Actually/really, if heat and power plant works in parallel with power system, then, regulating admission of steam into its turbines in accordance with heat requirement for the needs of district heating, we obtain some specific electric energy generation. If a quantity of generated at station electric power exceeds the requirement for it of local users, then the part of electric power is transmitted to the network/grid of power system with the appropriate simultaneous decrease of the load of other in parallel working power plants (he is regulated by the dispatcher of power system, see §3-4). On the other hand, if a quantity of developed electric power is insufficient for coating of the requirement of the local users of station, then supplementary electric power takes away/gathers from the network/grid of power system with the the simultaneous corresponding increase in the load of other power plants of system.

Is such a somewhat simplified picture of the control of the mode/conditions of the work of heat and power plant in power system. In the various operating cycles of one or the other power system, which has its special features/peculiarities, deviate from the control of mode/conditions the work of heat and power plant for the graph/curve of thermal consumption and increase the electrical load of heat and power plant over that electrical power, which its

aggregates/units develop with work on the graph/curve of thermal consumption (in the limits of the nominal power of aggregates/units) with the appropriate increase of the passage of steam into turbine condensers. Such modes/conditions of the work of individual heat and power plants sometimes can be justified by working conditions of power system as a whole, and sometimes also by the conditions of providing the steadiness of the power supply of users.

At the same time one should consider that on heat and power plants, especially on those which work on imported fuel/propellant, the prime cost of electric power, developed in condensation mode/conditions, as a rule, proves to be higher, rather than on the powerful/thick thermal district power plants, which work on local fuel/propellant, but all the more on hydroelectric stations. Exception/elimination can be the powerful/thick heat and power plants, which work on very cheap natural gas.

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The supply with thermal and electrical energy of users from heat and power plants, i.e., combined consumption/production/generation on heat and power plants of both forms of energy, gives the considerable fuel economy, sometimes which reaches by 15-25o/o in comparison with the fuel consumption with separate powering, i.e., with the electric

power supply from condensation power plants and heat supply from special boiler installations [2-1].

Centralized heat supply by hot water and vapor from heat and power plants makes it possible to eliminate the numerous small/fine uneconomical heating and industrial boiler installation of the users who moreover, frequently work on long-range high-energy propellant.

Heat and power plants usually are installed in immediate proximity to users; therefore electric power of them is distributed in essence over generator voltage 6 or 10 kV, as shown in diagram in Fig. 2-6. For the nourishment of the distant users, and also for the connection/communication of station with the electric system of power system on heat and power plants usually install the raising substation with secondary voltage 35 or 110 kV.

The possibility of the wide application of gas on power plants creates favorable ones conditions for positioning/arranging the heat and power plants directly in cities.

On Soviet heat and power plants are installed central heating turbine units in power to 50 MW inclusively. Is projected/designed the central heating turbine unit with a power of 100 MW.

From the examination of the technological process of steam turbine power plants it is evident, what large number of different auxiliary (official) mechanisms services/maintains the production process of thermal power plants. For the drive of these mechanisms are applied predominantly squirrel-cages motor.

The stop of some of the mechanisms, even to small period, entails either dead lock of aggregate/unit or considerable decrease in its load. For example, the stop of blast fan, exhaust fan or feed pump entails the stop of the boiler; the stop of circulation or condensate pump leads to the need for the stop of turbine unit, etc.

Electrical stations with engines install small power as agricultural stations, stations on forest exploitations and the like when it is not possible to obtain electric power from any powerful/thick station and when, in a sufficient quantity, fuel/propellant is present, for engines - local solid fuel or most frequently withdrawals/departures from the production - agricultural, woodworking, etc.

Engine is the aggregate/unit, which consists of steam boiler from thin and steam machine.

Steam from boiler it enters steam engine which with the aid of

belt drive revolves electric generator. The generators of such stations, as a rule, have voltage to 380/220 V and less than 6 kV, if it is necessary to supply users in a radius of several kilometers. Efficiency of stations with engines approximately/exemplarily 11-12o/o.

Power plants with internal combustion engines are installed also comparatively small power, usually into several hundred, maximum of thousands of kilowatts, and only when the power supply of users cannot be realized from local exchanges and when according to local conditions cannot be constructed steam station with engines or hydroelectric stations. As primary motor/engines can be used any internal combustion engines, but most frequently are applied diesels. These engines can work on liquid propellant (oil, petroleum residue) and gas.

The efficiency of power plants with diesels attains 32-33o/o. If we utilize waste heat for preheating water, necessary for public-service (bath, laundry, etc.) or production needs, then plant efficiency can be somewhat increased.

In the presence of local solid fuel is possible the installation of station with the internal combustion engines, gas-fired, obtained in gas generator units. In gas generator the solid fuel burns with an

insufficient quantity of air, as a result of which is formed the combustible gas, utilized in internal combustion engines. Gas generators can work on any local fuel/propellant and any organic industrial wastes - agricultural, woodworking, etc.

2-3. Hydroelectric stations.

The water in river, which takes place in direction from source to mouth, gradually trips (seemingly it falls) from certain height to the mark, which corresponds to the level of its mouth. In this case the water completes the work, connected mainly with eroding/scouring of soil and its displacement/movement in the direction of the flow of river, and also with the assumption of frictional forces between randomly moving/driving particles of water within flow itself. The greater the flow of river and the gradient of its river bed, the greater energy of water flow. Flow call the total space of water, which takes place during any time (days, month, year) through this alignment (section) rivers.

Hydroelectric stations are installations in which water energy is utilized for the production of electric power.

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Primary motor/engines of electric generators on hydroelectric power plants are the hydroturbines in which potential and kinetic hydraulic power is converted into the mechanical energy, utilized for rotating the generators.

The power, developed by a hydroturbine (net power on its shaft), depends on a quantity of passing through it water and value of the pressure head:

$$P_{\tau}=1\,000\ QH\eta_{c}\eta_{\tau}\quad [\text{kg-m/s}], \qquad (2.1)$$

where Q - a quantity of water, passing through the turbine, the m^3/s;

H - value of the pressure head (depth of fall) of water, m;

η_c - efficiency of the water supply installations, which considers loss of head in them (for example, in tubes, on which the water is fed/conducted to turbine and is abstracted/removed from it);

η_{τ}- efficiency of hydroturbine (for the hydroturbines of average and large power 0.88-0.94).

It is known that 1 kW=102 kg-m/s; therefore electrical terminal horsepower

$$P_г = \frac{1\,000QH}{102}\eta_c\eta_т\eta_г = 9{,}81QH\eta \text{ [kW]}, \quad (2-2)$$

where $\eta_г$ - efficiency of hydraulic generator (for the hydraulic generators of average and large power 0.95-0.98);

$\eta = \eta_c\eta_т\eta_г$ - efficiency of the hydroelectric power plant (for contemporary hydroelectric power plants it reaches value of 0.85-0.86).

From formula (2-2) it is possible to draw the conclusion that the power of hydroelectric power plant is determined by the available expenditure/consumption of water Q and by the value of pressure head H: the greater these values, large power can develop the aggregates/units of station.

On the hydroelectric power plants, planned on plains rivers, the necessary pressure head H is created by dam, and in certain cases and by the building of station, which adjoins the dam and by its being as continuation (Fig. 2-7).

The water area before dam 3 is called headwater 1, but below dams - by lower reach 2. The existence of phases of the levels of the

upper and lower reaches is pressure head H of installation. The higher the dam, the greater the pressure head H and, consequently, also the power of hydroelectric power plant.

From the side of the headwater usually are formed the reservoir, employee for the accumulation of the water, utilized in proportion to necessity for electric energy generation. With an increase in altitude of dam increases the space of reservoir.

Plains of rivers have comparatively flat and low shores; therefore the creation on them of the high pressure heads H is hindered/hampered by the fact that to ten and hundreds of kilometers upstream occurs the considerable inundation by the reservoir of the coasts of the river; sometimes the width of reservoir reaches several ten kilometers. The creation of such reservoirs is connected with the need of cutting forests/scaffolding and the transference of a large number of villages and industrial enterprises, but sometimes also the small cities, arranged/located on the coasts of river and falling into flooded area. Sometimes it is necessary to partially reorganize railroads and railroad bridges, to create water-shielding installations (dam) for protection from the inundation of major enterprises, districts of the large/coarse cities, important for the agricultural production of the earth/ground.

In hydro-electric station on plains river are included: the dam, the building of station, navigable sluice.

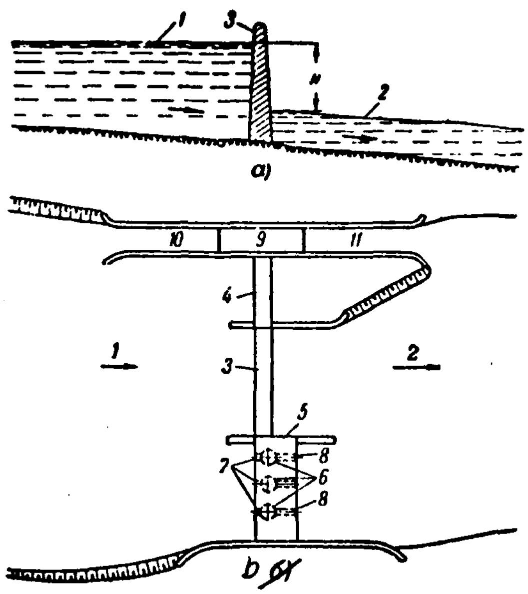

Fig. 2-7. Diagram of channel hydroelectric power plant. a) the diagram of the creation cf pressure head by the dam; b) the schematic plan/layout of hydro-electric station.

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Dam is the most critical and important installation of hydroelectric power plant. Dams are spillway and dead/blind.

Overfalls serve not only for the creation of the necessary pressure head, but also for discharge/break in the necessary reach of

overflow water with the overfilling of reservoir, which occurs mainly with seasonal floods. Overfalls, usually planned from concrete, have the water openings/apertures, overlapped with metallic panels or locks with the aid of which regulate discharge/break the water from the headwater into lower.

Dead/blind dams do not have water-outflow openings/apertures and serve only for the creation of the necessary pressure head. Dead/blind dams are concrete and earth. In recent years on the Soviet hydroelectric power plants, planned on plains rivers, use extensively dead/blind earth dams as most simple and cheap.

With small pressure heads the most widely used type of blind hydroelectric power plants are river-bed hydroelectric power plants (Fig. 2-7b), in which the building of station 5 enters into the general/common/total front of water-pressure installations, i.e., it appears as the continuation of dam (3 - concrete overfall; 4 - concrete dead/blind dam). Water to hydroturbines 6 is fed/conducted through inlets 7 and is abstracted/removed from the hydroturbines through suction tubes 8.

For the passage of ships serve single-chamber sluice 9 and approach channels 10 and 11.

An example of river-bed hydroelectric power plants are Uglichsk, Rybinsk and Gor'kiy GES in Volga and many others.

In recent years are installed the river-bed hydroelectric power plants, in which in the building of station are placed not only the openings/apertures for a water supply to hydroturbines, but also the water-outflow openings/apertures, normally-closed with panels or locks and which use for the discharge/break of flood water from the headwater. Therefore considerably is reduced the length of spillway concrete dam with the appropriate increase in the length of dead/blind earth dam, which gives the considerable savings of means and materials. Sometimes all water-outflow installations can be placed in the limits of machine room in the case of full/total/complete failure of the installation of spillway concrete dam.

An example of combined type river-bed stations are largest Volga of the name of V. I. Lenin and Stalingradskaya hydroelectric power plants in Volga.

With pressure heads more than 30-35 m usually install near-dam type hydroelectric power plants, whose building of station directly pressure head does not receive and is arranged/located after dead/blind concrete dam from the side of the lower reach (Fig. 2-8).

In the body of concrete dam 3 pass delivery conduits 9, on which the water from headwater 1 proceeds to hydrcturbines 8. This location of building accept by the series/row of stations, for example, on Dneprovsk hydroelectric power plant (calculated pressure head 38 m), on the projected fraternal hydroelectric power plant on hangar (calculated pressure head of approximately 100 m) and on many others.

Fig. 2-9 in the form of an example gives the cross section of near-dam hydroelectric power plant with the location of building 12 after dam 3, from the side of lower reach 2. Water from headwater 1 on delivery conduit 4 enters volute chamber 8, which encompasses the wheel of hydroturbine 9. From volute chamber the water enters impeller vanes of turbine, and then through suction tube 10 leaks off into the lower reach.

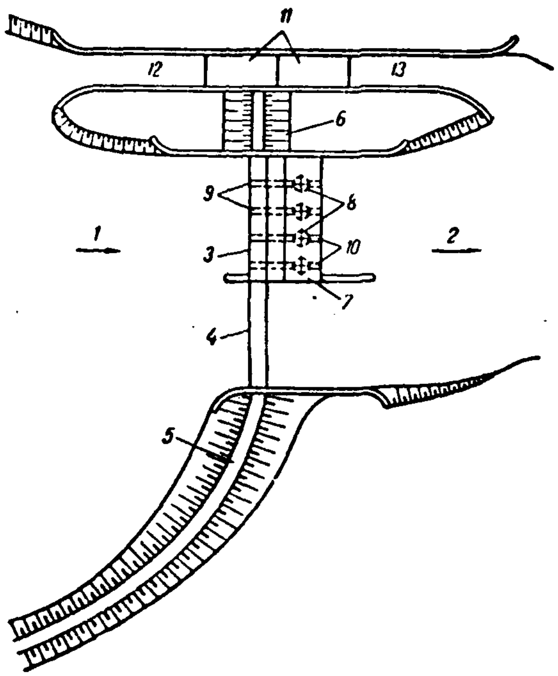

Fig. 2-8. Diagram of near-dam hydroelectric power plant. 1 - headwater; 2 - the lower reach; 3 - dead/blind concrete dam; 4 - spillway concrete dam; 5 and 6 - earth dams; 7 - building of the station; 8 - hydroturbine; 9 - pressurized pipelines; 10 - suction tubes; 11 - two-chamber sluice; 12 and 13 - approach channels.

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Volute chamber 8, which has the changing cross section, provides uniform water supply tc impeller of turbine and serves for the gradual translation/conversion of rectilinear forward motion of water

curvilinear.

The vertical shaft of turbine is connected with the vertical shaft of hydraulic generator 11, which is established/installed in machine room.

Manufactured by generator electric power enters the closed distributor of generator voltage 14, and from it into step-up transformer 15, established/installed in the open air. From transformer along aerial line 16 electric power enter the open distributor of the increased voltage (in Fig. 2-9 it is not shown), but from it into the network/grid of power system. Cable 17 shields aerial line from the direct impacts of lightning.

Lock 6 serves for the cessation of water inflow into delivery conduit 4. During repairs in slots/grooves 5 is omitted repair lock. Tap/crane 7 serves for settling and lifting the locks.

Machine room is equipped by bridge crane 13, necessary during mounting and repairs of aggregates/units.

On mountainous rivers the necessary pressure head can be created by using the considerable natural gradients (incidences/drops) of these rivers. let in range A (Fig. 2-10) bench mark of river compose

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H_A m above sea level, and in range B - respectively $H_Б$ m then in section AB the natural gradient of river, or, which is the same thing, a difference in the water levels in the beginning and end/lead of the section AB, comprises $H_p = H_A - H_Б$. Thus there is that difference in the horizons/levels (pressure head) and it is possible to utilize by installing a deviation hydroelectric power plant. Derivation installations, this of the installations, which go around fundamental river bead: diversion channels, tunnels, tubes.

The diagram of derivation installation is given in Fig. 2-10. In the beginning of the utilized section of river is arranged/located water intake 1, through which the water enters diversion channel 2, and from it into pressure basin 3. Dam 7 serves for providing the approach of water into diversion channel. The latter is laid with very small gradient, several times of smaller than natural gradient H_p of river in section AB. Therefore pressure head H on the turbines of hydroelectric power plant is temporarily less than gradient H_p.

From pressure basin 3 water along delivery pipes 4 enter hydroturbines, which are located in machine room 5. From hydroturbines the water along diverter 6 returns to river, but already in range B.

With the aid of dam 7 it is possible to create artificial reservoir with the specific water supply and to additionally raise water level, after increasing pressure head on the turbines of hydroelectric power plant.

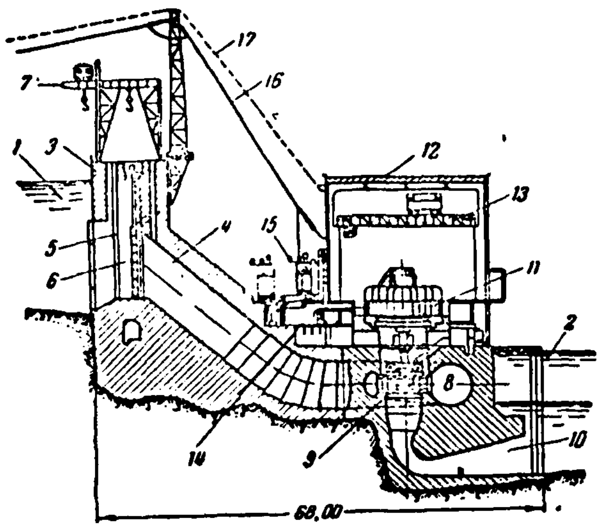

Fig. 2-9. The cross section of near-dam hydroelectric power plant.

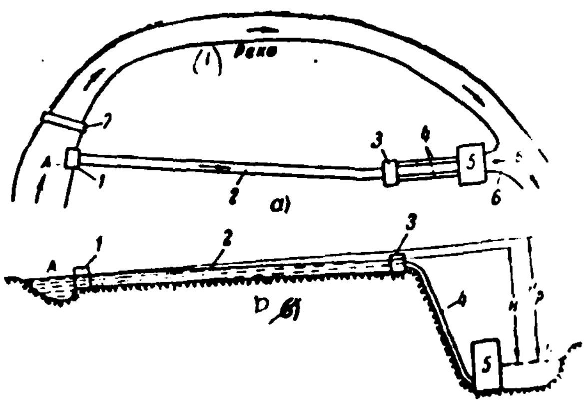

Fig. 2-10. Diagram of derivation hydroelectric power plant. a) the plan/layout of the hydro-electric station; b) the diagram of the

creation of pressure head.

Key: (1). River.

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Such installations in which the pressure head is partially created by dam and partially by derivation, call dead-derivation or mixed.

In derivation installation are included: 1) the head assembly, which consists of dam and water intake; 2) derivation installations - channels, tunnels, pipelines; 3) the station-type assembly into which enter pressure the basin and pipelines, building of station, diverter.

In the USSR are constructed several large/coarse derivation hydroelectric power plants, also, among them: the hydroelectric power plant of the Sevansk cascade/stage (on r. it is given) - Kanakersk, Ozernaya and Gyumushsk; Khramsk - on the river Khram; ZAGES - on the river Kur; Farkhads - in Central Asia; Niva-3 - in the Kol'skiy peninsula and a number of others.

Under conditions of planned socialist economy during the installation of hydroelectric power plants are solved not only energy

problems, but also complex of other important national-economic problems: an improvement in the navigation, irrigation and irrigation of the arid earth/ground, improvement in the water supply of cities and industrial enterprises. In certain cases through the water-engineering constructions of hydroelectric power plants run the highways and railway lines.

Hydroelectric power plants give to national economy the savings of a large quantity of fuel/propellant and free/release transport from its transport.

On hydroelectric power plants comparatively easily is realized the automation of the production process which is considerably simpler than the production process of thermal power plants (mainly as a result of the absence of fuel economy and boiler with all auxiliary services). There are fully automated hydroelectric power plants. On hydroelectric power plants is considerably less the volume of repair work. As a result of entire this the number of personnel on hydroelectric stations is considerably less than on thermal power plants of the same power.

Because of smaller operating costs the prime cost of manufactured electric power on hydroelectric power plants several times is less (usually 3-5 times), than on thermal power plants.

A large/coarse deficiency/lack in the hydroelectric power plants is the considerably larger cost/value of their installation in comparison with the thermal power plants of the same power, which is explained by the mainly large volume of earth and construction work during the installation of hydroelectric power plants. True, in the process of operating the hydroelectric power plants this difference in first costs fast enough is redeemed due to the smaller prime cost of electric power on hydroelectric stations.

An important deficiency/lack in the hydroelectric power plants are the large period of their installation, the considerably exceeding period of the installation of the same according to the power of thermal power plants.

Taking into account these deficiencies/lacks in the hydroelectric power plants and on the basis of the need to maximally accelerate the development of power engineering of the country, which more narrowly was discussed into §1-3, seven-year the plan/layout of the development of national economy for 1959-1965 provides for certain temporary/time reduction of the construction of hydroelectric power plants during the maximum development/scanning of the construction of powerful/thick thermal power plants.

The place of the installation of hydroelectric power plants is selected taking into account the most advisable use of energy of the water flow: attempt to obtain largest possible electric energy generation and the power of station with the minimum expenditures of materials and resources for the installation of hydraulic station, including expenditures for the preparation of the bed of the reservoir (see above), consider the conditions of navigation, irrigation, irrigation, water supply of cities and enterprises, etc.

Electric power, developed by the hydroelectric power plants of average and large power, is usually put out directly in electric system by the voltage 35-500 kV of power systems. In connection with this the diagrams of the electrical connections of the hydroelectric power plants of average and large power usually little differ from the diagrams of the electrical connections of thermal district power plants. The principle of the fulfillment of this diagram is given in Fig. 2-3: electric power 5E from generator 15 enters that raising of transformer 24, from the latter by collecting mains SSh of 35 kV and above, but from them in electric power line LEP.

Together with powerful/thick hydroelectric power plants in the USSR are installed small hydroelectric power plants by power from

several ten or hundreds of kilowatts to several thousand kilowatts, intended mainly for the electrification of rural economy and small cities in those regions where there is no power net of powerful/thick power plants.

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From these small hydroelectric stations, electric power is usually distributed directly over generator voltage to 10 kV inclusively and and less at the increased voltage 35 kV.

Run off in rivers during year changes and the greatest value it reaches during spring seasonal flood. The best use of energy of water flow is achieved, in the first place, with the artificial control of flow and, in the second place, with the multiple operation of hydroelectric and thermal power plants on the general/common/total electric system of power system.

If hydroelectric power plant does not have a reservoir (such stations are encountered comparatively rarely), then the mode of its operation is determined by the flow of river: with large flows the hydroelectric power plant can develop total power and put out into the network/grid of power system a large quantity of electric power with the appropriate decrease in the load of the thermal power plant

(see §3-4); on the other hand, at low run off the load of hydroplant is correspondingly decreased, and the greater load is transmitted to the thermal stations of the power system. On such hydroelectric power plants the large part of the water of spring seasonal flood is dumped through the dam, i.e., it is not utilized.

On hydroelectric power plants with reservoirs of a comparatively small volume usually is realized the so-called diurnal control of flow. In this case the water, accumulated in reservoir for the specific hours of days, utilize for electric energy generation comparatively short-term, for several hours in a 24 hour period, for providing the supply of users with full loads the systems when the power of thermal power plants it is insufficient (the so-called peak mode/conditions of operation of stations, see §3-4). In the remaining hours of day this hydroelectric power plant works with the fractional load, determined from the conditions of filling of reservoir and minimally necessary passage of water into lower bank (from the conditions of navigation, irrigation, water supply of enterprises and cities, etc.).

On hydroelectric power plants with the considerable space of reservoirs is realized the annual control of the flow when entire flood water, with exception of the water, expended by turbines of hydroelectric power plant, is delayed in the reservoir before the dam and then into remaining part the year gradually it is expended/consumed into addition to the natural summer and winter

flows of river. On such hydroelectric power plants can be realized also diurnal of control as this is shown above.

On hydroelectric power plants with the reservoirs of a comparatively small volume usually is realized the so-called diurnal control of flow. In this case the water, accumulated in reservoir for the specific hours of day, utilize for electric energy generation is comparatively short-term, for several hours in a 24 hour period, for providing the supply of users with full loads the systems when the power of thermal power plants it is insufficient (the so-called peak mode/conditions of operation of stations, see §3-4). In the remaining hours of day this hydroelectric power plant works with the fractional load, determined from the conditions of filling of reservoir and minimally necessary passage of water into the lower reach (from the conditions of navigation, irrigation, water supply of enterprises and cities, etc.).

On hydroelectric power plants with the considerable space of reservoirs is realized the annual control of the flow when entire flood water, with exception of the water, expended by turbines of hydroelectric power plant, is delayed in the reservoir before the dam and then into the remaining part of the year gradually is expended/consumed into addition to the natural summer and winter flows of river. On such hydroelectric power plants can be realized

also diurnal control as this is shown above.

In certain cases the space of the reservoir of hydroelectric power plants on plains rivers does not permit implemention of full/total/complete annual control of flow. At such stations is realized the seasonal control when in reservoir is delayed only the part of the flood water; remaining part flood of water is dumped through the dam into the lower reach. The delayed in reservoir water is utilized usually in the winter months when flow in river has minimum value. Therefore in winter months the hydroelectric power plant can bear large load.

By the control of flow is provided the more complete utilization of energy of water flow and, consequently, also large electric energy generation on hydroelectric power plant, as a result of which are reached considerable fuel economy and reduction in the prime cost of electric power in system.

2-4. The atomic power plants.

In 1954 in the USSR was introduced in operation the first in the world atomic power plant in power 5000 kW, using intranuclear energy for electric energy generation in industrial purposes. Was made the first step/pitch in mastery/adoption for the energy purposes of

energy of atomic nucleus.

In 1958 was started the first turn by the power of 100 MW of the second atomic power plant whose total power will be 600 MW.

Fig. 2-11 gives the simplified schematic diagram of the first atomic power plant from which it is evident that the atomic stations are actually thermal steam-turbine power plants whose role of boiler unit perform nuclear reactor 1 and steam generator 4.

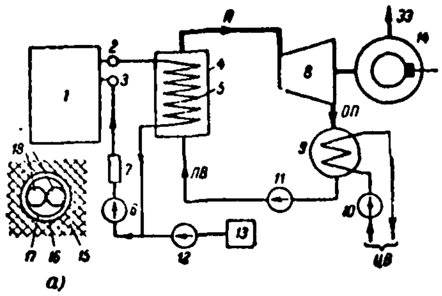

Fig. 2-11. The simplified circuit of the atomic power plant. a) the schematic of the working channel of atomic reactor.

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As electric power source is utilized the usual turbine unit, which consists of steam turbine 8 and turbogenerator 14.

The energy source on the first atomic power plant is nuclear reactor 1, in which occurs the fission chain reaction of the nuclei of uranium-235 by slow neutrons. As neutron moderator is used graphite.

Reactor core is made from graphite by 15 in the form of vertical cylinder with a large number of vertical openings/apertures. Into these openings/apertures are inserted the so-called working (technological) channels. The very simplified circuit of this channel

is shown on outline a Fig. 2-11: channel consists of thin-walled steel tube with 16, inside which is inserted plug 17 of uranium in the form of the special alloy; within latter/last is placed U-shaped thin-walled steel tube with 18, on which flows/occurs/lasts the water. Over one half tube the water flows/occurs/lasts downward, while on another it returns upward. In the upper part of the reactor the ends/leads of these U-shaped tubes of all channels are connected into collectors/receptacles 2 and 3 [2-2].

In process the nuclear fissions of uranium of plug 17 are heated and is given up heat to the water, which takes place in tubes with 18. The circulation of the water through the reactor is continuously supported by pump 6.

In all in the reactor of 128 working channels in long on 7 m. Them replaces on measure the "burn-out" of the fissionable substance.

The intensity of reaction, and thereby also energy content, which separates in reactor, are regulated by the splash cores, made from material, that actively absorbing neutrons. Is achieved this by position control of the rods indicated in special vertical reactor channels.

As can be seen from diagram in Fig. 2-11, at station are

realized two independent circulation loops of water.

Of the first outline, which consists of reactor 1 and tubes 5 of steam generator 4, under the action of circulating pump 6 always circulates one and the same space of the distilled water, which is located under pressure 100 atm(tech). Passing on tubes 18 reactors, water is heated to 270°C and then it enters steam generator 4, where it gives up its heat to water and the steam of secondary circuit. From steam generator the water with pump 6 is supplied into reactor. Filter 7 serves for warning/preventing the incidence/impingement into the reactor of the random weighed solid particles.

The replacement of water in the first outline and the completion/replenishment of losses as a result of possible escapes are realized from tank by 13 with the aid of pump 12.

Secondary circuit consists of steam generator 4, steam turbine 8 and capacitor/condenser 9.

Forming in steam generator of steam at a pressure 12.5 atm(abs.) and temperature 260°C enters steam turbine and from it into the capacitor/condenser where it is cooled by circulation water by TsV, supplied with pump 10. Feed pump 11 supplies condensate from capacitor/condenser into steam generator.

With the work of nuclear reactor appear the radioactive radiations, moreover special danger for people represent neutrons and gamma-rays, in large quantities generated by reactor. In order to fence the service personnel from the harmful effect of neutrons and gamma-rays, reactor is surrounded by the protection which consists of the layers of water (with a thickness of 1 m), concrete (with a thickness of 3 m) and cast iron (with a thickness of 0.25 m).

Primary water, passing through the reactor, acquires radioactivity. Water of its secondary circuit does not have. Consequently, by the use/application of two circulation loops of water is provided the safety of servicing turbine and its accessory equipment.

All the equipment of the first outline (steam generator 4, pump 6, etc.) is placed in the separate shielded cabins.

In all at the stations are established/installed four steam generators, of which one - stand-by. With load of 5000 kW the station expends/consumes in the days of approximately/exemplarily 30 g of uranium. The steam-turbine condensation power plant of the same power and with the same load expends/consumes in a 24 hour period to

100-110 t of Moscow brown coal.

The atomic power plants can be installed both with the condensation ones and with central heating turbines. With respect to this their thermal circuits can be fulfilled analogously with the diagrams, given in Fig. 2-3 or 2-6.

In 1959-1965 in the USSR will be constructed several large/coarse atomic power plants. This they will be of power plant in power on 400-600 MW, and possibly also more powerful/thick.

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For gaining of the experience of construction and operation are installed the power plants from somewhat different flow charts and turbine units of different power in the different initial parameters of steam. Large/coarse power plants will be equipped by the reactors, which use as heat-transfer agent and neutron moderator usual pressurized water, and by the reactors, which use an ordinary water or steam as heat-transfer agent and graphite as retarder.

Installation in the future of powerful/thick atomic power plants, especially in regions, which do not have local fuel/propellant and not having available the sources of hydroelectric energy, will be a powerful stimulus of further development of Soviet power engineering and all fields of the national economy of the USSR.

Chapter Three.

GENERAL INFORMATION ABOUT ELECTRICS OF THE POWER PLANTS AND POWER SYSTEMS.

3-1. Systems of current. Nominal voltages.

Electric power, developed by power plants, they transmit to different distances depending on the distance of power plants from the users of electric power. The greater the extent of the lines of electric system and the transmitted by them electrical power, the more advantageous it is to transmit electric power with high voltage.

With an increase in the voltage in the wires of electric system decreases, as a result of which the same electrical power can be transmitted by the wires of smaller sections. Decrease energy losses in electric system.

Since electric generators and receivers are constructed to the specific standard voltages (see below), then during the construction of the electric systems of high voltage is usually necessary to change voltage, and sometimes several times (see Fig. 3-5 and 3-8). Most simply and economically such conversions of voltage are realized

with alternating current with the aid of power transformers. At the same time one ought not to conclude that it is always necessary to approach the use/application of high voltages. The fact is that in proportion to an increase in the voltage grow/rise both the initial expenditures for the construction of network/grid and transformer substations and the expenditures for their maintenance/servicing. Therefore at certain value of high voltage the supplementary expenditures/consumptions indicated will not already covered by savings from the decrease of the energy losses and section of wires. In each individual case the highest voltage is determined by the appropriate technical-economic calculations.

In the USSR for production and electrical power distribution is accepted alternating three-phase current with the frequency of 50 Hz. The use/application of a three-phase current is explained, in the first place, by the larger efficiency/cost-effectiveness of networks/grids and installations of three-phase current in comparison with networks/grids and by the installations of single-phase alternating current and, in the second place, by the possibility of use/application in the industry of the three-phase asynchronous electric motors, which are most reliable, cheap and simple of all existing types of electric motors.

In a number of the branches of industry together with

three-phase current is applied direct current for electric drive, electrolysis in chemical industry and nonferrous metallurgy (production of aluminum, zinc, etc.) and other purposes.

The electric motors of direct current are applied when according to the conditions for technological process is necessary the wide and steady control of the rate of production mechanisms. Furthermore, direct current is used extensively for the electrified transport. The users indicated they usually supply by direct current from the rotary substations, which convert three-phase current into current constant. As converters most are used extensively the mercury-arc rectifiers.

The direct current of very high voltages can find use for the transmission of large power up to very large distances. Since on power plants is developed electric power of three-phase current, then with the realization of power transmission of direct current is necessary construction on the feeding side of the transmission not only of the raising transformer substation, which uses for obtaining necessary high voltage of transmission, but also rectifying installation, which converts alternating current into direct high-tension current.

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At receiving end of the transmission is necessary the construction both the inverter installation, which converts direct current into alternating high-tension current and lowers transformer substation. Thus, and in this case production and electrical power distribution are realized by a three-phase current, and only very electric power line works on direct current.

In the Soviet Union from 1950 works the experimental production electric power line of direct current by voltage 200 kV Kashira - Moscow with a length of 112 km by which is transmitted the power of 30 MW.

In 1959-1960 will be constructed the electric power line of direct current by voltage 800 kV from Stalingrad hydroelectric power plant into Donbass.

The accepted to the USSR standard voltages for the fixed systems of heavy current are given in Table 3-1 (according to GOST 721-41).

Nominal the voltage of the receivers of electric power (electric motors, tubes, etc.), generators and transformers is called the voltage, with which they are intended for a normal operation.

Electrical network is characterized by the nominal voltage of

the receivers of electric power which from it are supplied; therefore for the nominal voltage of its electrical receivers.

The nominal voltages of electric generators are accepted to 5o/o higher than nominal voltages of the corresponding electric systems how is considered the loss of line voltage with their normal load. For powerful/thick turbo- and hydraulic generators of Soviet production are applied also voltages 11; 13.8; 15.75 and 18 kV (see tables P-1 and P-2 [1]).

FOOTNOTE [1]. The tables, designated by the letter P, are given in appendices. ENDFOOTNOTE.

In this case to the same voltages are performed the primary windings of the step-up and step-down transformers, connected directly to the outputs of generators.

The nominal voltages of the primary windings of the step-down transformers are equal to the nominal voltages of the corresponding electric systems, i.e., electrical receivers, with exception of the voltages, noted in Table 3-1 by asterisk, which are related to the step-up and step-down transformers, connected directly to collecting mains or outputs of generators.

The nominal voltage of secondary winding of transformer they will be determined with the idling of transformer, i.e., with the idling of transformer, i.e., with its extended secondary winding and nominal voltage in primary winding. Taking into account the losses of the voltage of secondary windings of transformers (Table 3-1) on 5 or 10o/o higher than nominal voltages of the corresponding electric systems (electrical receivers).

Direct current by voltage 110 and 220 V apply in the installations of its own needs of power plants to large/coarse substations for the feed of the circuits of relaying, automation, emergency light, signaling and so forth, etc.

The electric motors of direct current are applied normally on 220 and 440 V.

For the installations of the direct current of special designation/purpose (thrust/rod, electrolysis, etc.) frequently are applied voltage different from those given and established/installed by special standards.

Table 3-1. Nominal voltages.

(1) Номинальное напряжение приемников электроэнергии, в			(2) Номинальное напряжение, в					
			(4) Генераторов		(5) Трансформаторов			
(8) Постоянного тока	(3) Трехфазного тока 50 гц				(6) Трехфазного тока 50 гц (междуфазное)		(7) Однофазного тока 50 гц	
	(9) Междуфазное	(10) Фазное	(8) Постоянного тока	(3) Трехфазного тока 50 гц (междуфазное)	(11) Первичные обмотки	(12) Вторичные обмотки	(11) Первичные обмотки	(12) Вторичные обмотки
110	—	—	115	—	—	—	—	—
—	127	—	—	133	127	133	127	133
220	220	127	230	230	220	230	220	230
—	380	220	—	400	380	400	380	—
440	—	—	460	—	—	—	—	—
—	500	—	—	525	500	525	500	—
—	3 000	—	—	3 150	3 000 и 3 150*	3 150 и 3 300	—	—
—	6 000	—	—	6 300	6 000 и 6 300*	6 300 и 6 600	—	—
—	10 000	—	—	10 500	10 000 и 10 500*	10 500 и 11000	—	—
—	35 000	—	—	—	35 000	38 500	—	—
—	110 000	—	—	—	110 000	121000	—	—
—	154 000	—	—	—	154 000	169000	—	—
—	220 000	—	—	—	220 000	242000	—	—

Key (1). Nominal voltage of the receivers of electric power. (2). Nominal voltage, V. (3). Three-phase current 50 ~~GA~~ Hz. (4). Generators. (5). Transformers. (6). Three-phase current 50 ~~GA~~ Hz (interphase). (7). Single-phase current 50 ~~kg.~~ Hz. (8). Direct current. (9). Interphase. (10). Phase. (11). primary windings. (12). Secondary windings.

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For the feed of electrical illuminating installations normally are installed four-wire electric systems by voltage 380/220 V (three phases and zero or neutral wire, with the inclusion/connection of tubes to phase voltage 220 V). Three-wire networks/grids by voltage 127 and 220 V for new installations are not recommended as a result of the considerably larger cost/value of the electric systems of these voltages in comparison with the cost/value of electric systems with voltage 380/220 V (with smaller voltage necessarily the larger section of wires).

Four-wire electric systems by voltage 220/127 V usually somewhat more expensive than networks/grids 380/220 V; however, at voltage 220/127 V is achieved the considerable decrease of operating costs due to larger efficiency/cost-effectiveness and larger service life incandescent lamp to voltage 127 V. Therefore sometimes for electrical illuminating installations economically more advisable can prove to be voltage 220/127 V [L. 3-1].

Neutral wires of four-wire networks/grids by voltage 380/220 and

220/127 V in Soviet practice accept to ground tightly for guaranteeing the automatic cutoff/disconnection of the element/cell of installation or section of network/grid during single-phase closing/shorting to the earth and increases in the safety of servicing of these networks/grids [L, 3-2].

Let us examine the case when the neutral of this network/grid is not grounded (Fig. 3-1a). during dead/blind (metallic, i.e., with negligibly low contact resistance) closing/shorting to the earth of one of the phases, for example phase C at point K, safety fuse P of this phase it does not burn out, since the current of closing/shorting to the earth in such networks/grids is small (see also §5-1), and voltages with respect to the earth/ground of two other phases long prove to be equal to interphase voltage (respectively 380 or 220 V). Under this voltage falls the man, if he stands on the earth/ground and touches by hand and to uninsulated section of one of the phases with intact/uninjured/undamaged insulation with respect to the earth/ground.

But if the neutral of four-wire network/grid is grounded tightly (Fig. 3-1b), then during dead/blind closing/shorting to the earth of one of the phases appears single-phase short circuit (through the earth/ground) and the damaged phase is disconnected as a result of the burn-out of the established/installed on it safety fuse P (or the

cutoff/disconnection of its shielding automatic switch, see chapter 15). The voltages of intact/uninjured/undamaged phases with respect to the earth/ground remain equal to phase, i.e., 220 or 127 V. In this network/grid of man, touching the uninsulated section of any phase, it can prove to be only under phase voltage, i.e., respectively under voltage 220 V in networks/grids 380/220 V and 127 V in networks/grids 220/127 V.

For the electric motors of low power most frequently is used the voltage 380 V more rarely than 220 and 500 V. To voltage 3 kV apply electric motors in power 75 kW and more, while to voltage 6 kV - power 200-250 kW and more. To voltage 10 kV are applied very large power motors by power into several thousand kilowatts.

Electric systems urban ones and major industrial enterprises make to voltages 6 or 10 kV. Practice also introduction/input in the territory of large cities and enterprises of the lines of transmission networks by voltage 35 and 110 kV (the so-called deep introductions/inputs), which feed the powerful/thick reducing substations, from which already with voltage 6 or 10 kV are supplied urban or industrial electric systems.

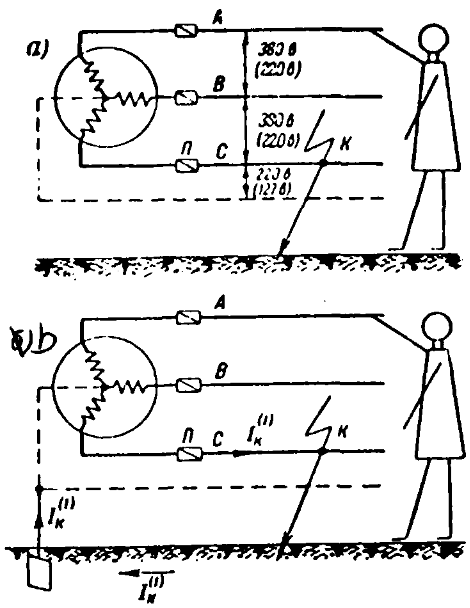

Fig. 3-1. Three-phase four-wire network/grid by voltage 380/220 or 220/127 V. a) with the ungrounded neutral; b) with grounded neutral.

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Voltages 35 kV and above are applied for the electric power lines of district electric systems, then by which electric power is transmitted to considerable distances - to ten and hundreds of kilometers. Besides the voltages 35-220 kV, indicat[illegible] n Table 3-1, in the USSR is applied also nominal voltage 400 kV, on which work the electric power lines from Volga hydroelectric power plant of the name of V. I. Lenin to Moscow and Chelyabinsk. In 1957 the Ministry of the

power plants of the USSR made a decision all new electric power lines of large extent and as capacity on the order of 650 MW and to more install to voltage 500 kV. Foundation for this is the fact that with a comparatively small increase in the capital expenditures the capacity of power transmission for voltage 500 kV to 25-40o/o is more than transmission in voltage 400 kV [L. 3-3 and 3-4].

It is planned to also apply nominal voltage 330 kV. In particular, voltage 330 kV accept for the planned in Dniepr Kremenchug hydroelectric power plant.

All electrical devices conditionally it is possible to subdivide into two groups: electrical devices by voltage to 1000 V and by voltage it is above 1000 V as this provided in the active "rules of the device/equipment of electrical devices" (PUE) and the "safety regulations" (PTB) [L. 3-5 and 3-6]. This subdivision is caused by differences in construction/design and insulation of electrical equipment (electrical machines, apparatuses, cables, insulators, etc.), in the execution of distributors and in the rules of construction and operation of the groups of electrical devices indicated.

At the same time in practice conventional is also the separation into electrical devices and electrical equipment of low and high

voltage (low-voltage and high-voltage). In the following presentation we also frequently use these conditional terms, understanding by low-voltage ones all devices/equipment by voltage to 1000 V, but under high-voltage ones - by a voltage are above 1000 V. In this case one should remember that this subdivision is purely conditional and completely it does not reflect the degree of the safety of servicing the installations of one or the other voltage.

3-2. General information about electrical circuits and electrical equipment of electrical stations and substations.

For the purpose of the facilitation of the understanding of the subsequent sections of course let us become acquainted with the simplest diagrams of the electrical connections of stations and substations of high voltage and the designation/purpose of the fundamental used on them electrical equipment.

The schematic of the electrical connections of electrical device in the conventional designations shows all its fundamental elements/cells (circuits of generators, of power transformers and electric motors, collecting mains, waste/exiting lines, etc.) and their fundamental electrical equipment (disconnecting equipment, instrument transformers, reactors, etc.), and also all connections between aggregates/units and apparatuses in that sequence, in which

they are carried out in actuality.

Are distinguished unilinear and trilinear diagrams. In unilinear diagrams conditionally show connections only for one phase the installations, which simplifies diagram and gives to it clarity. In schematic unilinear diagrams indicate only the fundamental aggregates/units of the installation: generators, power transformers, electric motors (Fig. 3-5). In more detailed unilinear diagrams indicate also the disconnecting apparatuses, instrument transformers, busbar/tire and cable joints, measuring meters, relay of protection and automation, etc. Such diagrams give general idea about electrical device and established/installed on it fundamental electrical equipment (for example, diagram in Fig. 3-2, where for the purpose of simplification are not shown measuring meters, relay of protection and automation, instruments of signaling, etc.).

Trilinear diagrams comprise for all three phases (see Fig. 3-3) with the indication of entire electrical equipment of primary circuits, and also all measuring meters, instruments of signaling, relay of protection and automation and so forth, etc. In trilinear diagrams indicate also all connections of secondary circuits, i.e., the connections of measuring meters with instrument transformers, the connections of the relay of protection and automation, signaling, etc.

The diagrams of electrical connections are made with the necessary use of the established/installed by GOST 7624-55 conditional graphic designations. Some of these designations, relating to the diagrams of primary circuits and most frequently encountering in this book, are given in Table 3-2.

The conventional designations of the elements of the networks of secondary circuits are given in the second volume.

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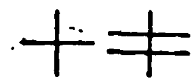
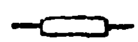
Table 3-2. Some conditional graphic designations in electrical circuits according to GOST 7621-55.

(1) Наименование элемента	(2) Условное обозначение
(3) Электрическое соединение шин или проводов	
(4) Провода или шины пересекаются, но электрически не соединены	
(5) Заземление (соединение с землей)	
(6) Контакт аппарата, зажим на сборке	
(7) Кабельная разделка	
(8) Реактор	
(9) Трансформатор тока с одним сердечником	
(10) То же, но с двумя сердечниками (двумя вторичными обмотками)	
(11) Плавкий предохранитель	
(12) Сопротивление нерегулируемое	
(13) Сопротивление регулируемое без разрыва цепи со скользящими контактами	

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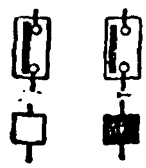
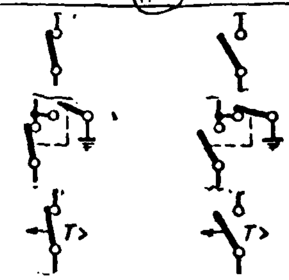
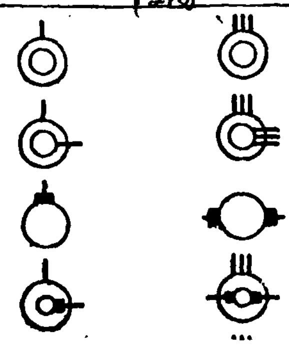
	(14) Положение	
	(16) включено	(17) отключено
(15) *Отключающие аппараты*		
(18) Выключатель высокого напряжения (масляный, воздушный, автогазовый и др.)		
(19) То же, но упрощенное обозначение		



(7) Наименование элемента	(20) Условное обозначение	
	(14) Положение	
	(16) включено	(17) отключено
(21) Разъединитель, рубильник		
(22) Разъединитель с заземляющим ножом		
(23) Автомат максимального тока		
(24) *Электрические машины и трансформаторы*	(24a) в однолинейных схемах	(24b) в многолинейных схемах
(25) Электродвигатель асинхронный трехфазный с короткозамкнутым ротором		
(26) То же, но с фазным ротором		
(27) Генератор постоянного тока		
(28) Синхронный генератор трехфазного тока		





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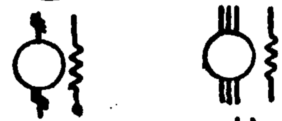
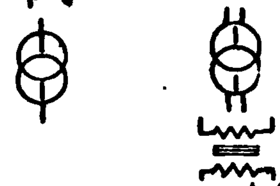
(19) То же, но упрощенное обозначение

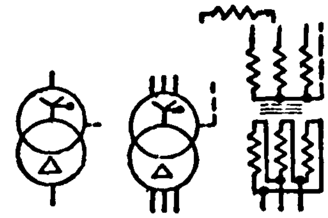
(29) Синхронный генератор с выведенными шестью концами фаз обмотки статора и с указанием обмотки возбуждения



(30) Трансформатор однофазный с сердечником



(31) Трансформатор трехфазный двухобмоточный с сердечником, с соединением обмоток звезда — треугольник, с выведенной нейтралью



(32) Автотрансформатор трехфазный с сердечником, с соединением обмоток в звезду

Key: (1). The designation of element/cell. (2). Conventional designations. (3). Electrical connection of busbars or wires. (4). wires or busbars intersect, but it is not electrically connected. (5). Grounding (ground connection). (6). Contact of apparatus, terminal/gripper on assembly. (7). Cable preparing. (8). Reactor. (9). Current transformer with one core. (10). Then, but with two cores (two secondary windings). (11). Safety fuse. (12). Resistor/resistance, fixed. (13). Resistor/resistance, adjusted without chain cleavage with slipping contacts. (14). Position. (15). Disconnecting apparatuses. (16). it is connected. (17). it is disconnected. (18). High-voltage switch (oil, air, auto-gas, etc.). (19). Then, but simplified designation. (20). Conventional designations. (21). Disconnector, knife switch. (22). Disconnector with grounding knife. (23). Automaton of maximum current. (24). Electrical machines and transformers. (24a). in unilinear diagrams. (24b). in multilinear diagrams. (25). Electric motor asynchronous three-phase with short-circuited rotor. (26). Then, but with phase-wound rotor. (27). Direct-current generator. (28). Synchronous threephase generator. (29). Alternator with brought-out six ends/leads of phases of stator winding and with indication of excitation winding. (30). Transformer (single-phase with core). (31). Transformer three-phase double wound with core, with connection of windings star - triangle, with brought-out neutral. (32). Autotransformer three-phase with core, with connection of windings into star.

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Let us note also that in our practice accept by the nominal voltage of electrical device (station, substation) to count the nominal voltage of the electric system, which feeds from this installation. Therefore on the diagrams of connections of electric installations (on their collecting mains) should be indicated the nominal voltages of the corresponding networks/grids according to GOST (see Table 3-1), i.e., the nominal voltages of electrical receivers (for example, 6, 10 kV, etc.), but not the nominal voltages of generators or secondary windings of power transformers.

Fig. 3-2 gives line diagram of the power plant of comparatively small power with two generators of nominal voltage 6.3 kV. Developed by generators electric power enters the collecting mains SSh and from them into cable system 6 kV.

Dotted lines in the diagram limited the outlines of those locations in which is established/installed the corresponding equipment. Generators G-1 and G-2 together with their primary motor/engines (in the diagram they are not shown) are

established/installed in the machine room of the main housing of station. Entire electrical equipment by voltage 6 kV is established/installed in the main distributor device/equipment 6 kV of station. Generators are connected with distributor by busbars on the insulators; sometimes this connection is made by power cables. The waste/exiting lines 6 kV are carried out by cables.

Step-down power transformers T-1 and T-2 serve for the feed of the distributing frame 380/220 V of the installation of their own needs of station. From the busbars of this panel will move away the lines, which feed the electric motors of the mechanisms of their own needs and the electric lighting of station.

In all circuits of station are established/installed the disconnecting apparatuses. In installations by voltage to 1000 V are applied the disconnecting apparatuses, indicated in the diagram in branch circuits 380/220 V: knife switches rub and safety fuses P or automatic air switches (automata) T> and other, disconnecting circuits during overloadings and short circuits (see Chapters 14 and 15).

In installations by voltage above 1000 V apply the disconnecting apparatuses, indicated in the diagram in branch circuits 6 kV: switches V, disconnectors R, safety fuses P (see Chapters 14, 16 and 17).

High-voltage switches serve for inclusion/connection and cutoff/disconnection of circuits during normal operation, and also for the automatic cutoff/disconnection of circuits during their damages. For control of switches are applied the drives (see Fig. 3-3), which serve also for the retention of switches in the connected position (see Chapter 18).

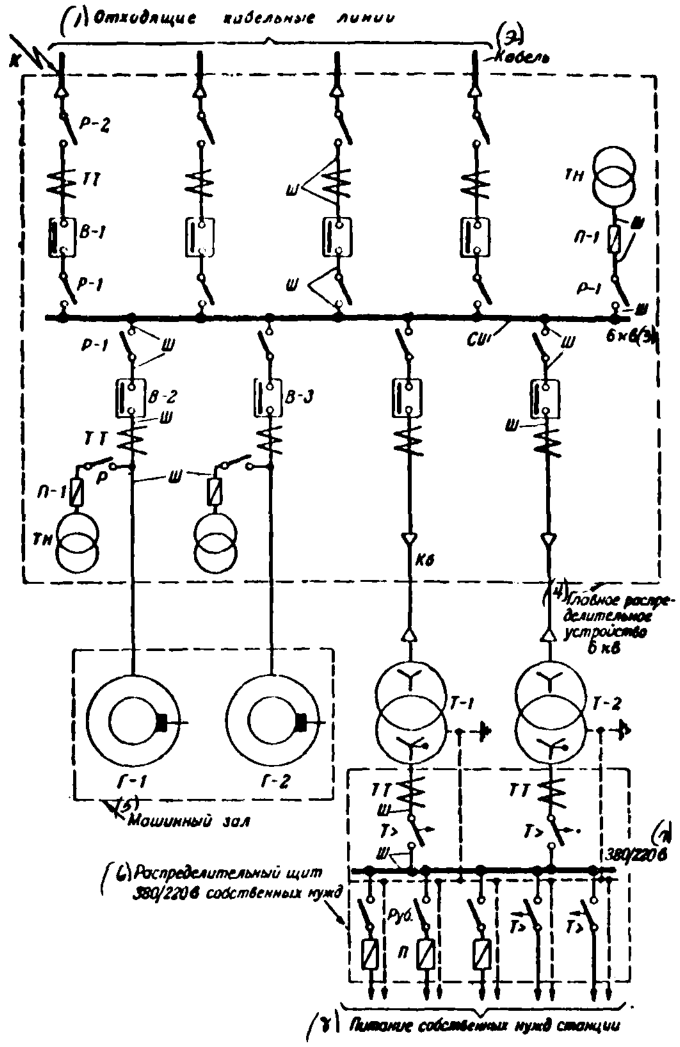

Fig. 3-2. Line diagram of power plant with one system of collecting mains.

Key: (1). Waste/exiting cable lines. (2). Cable. (3). kV. (4). Main distributor 6 kV. (5). Equipment hall. (6). distributing frame

380/220 V of its own needs. (7). V. (8). Feed of its own needs of station.

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So that the switches would automatically disconnect circuits with the disruptions of their normal operation, dangerous for electrical equipment, it is necessary that in each circuit would be established/installed relaying.

The fundamental problem of relaying is the rapid and reliable liquidation of emergencies and abnormal modes/conditions, which appear in electrical device, for the purpose of retention/preservation/maintaining in the work of all intact/uninjured/undamaged and normally working parts of the installation. Relay protection is fulfilled of one or several relays, i.e., the special instruments which during disturbance or damage of any element/cell of installation act on the drive of the switch of the corresponding circuit, after which the latter automatically is disconnected. In certain cases relayings actuate the signalling devices (bell, siren, tube), which notify personnel about the need of accepting the measures for the elimination of the abnormal operating mode.

Let us examine the operating principle of simplest and most widely used relaying, namely the maximum current protection from the currents of short circuiting, adjusted in the majority of circuits. The schematic trilinear diagram of this protection on the waste/exiting line is given in Fig. 3-3. The windings by relay are connected to secondary windings of current transformers; therefore in normal mode coil current by relay does not exceed 5 A and the cores of relay cannot be sucked inside coils and lock contacts. During short circuit at point K in primary circuit appears the short-circuit current, several times the exceeding operating current of circuit. In this case considerably increases the current in secondary windings of current transformers and windings by relay, as a result of which the cores are pulled and close contacts. Through the latter are closed the direct-current circuit of the disconnecting electromagnet of the drive of the switch (course of the current through the contacts of one relay is shown by broken rifleman/pointers), its core it is pulled by its striker it displaces retaining catch of drive. In this case the switch under the action of the disconnecting spring disconnects the circuit, in which occurred short circuit.

Relaying of electrical devices must operate selectively (it is selective), i.e., it must be so it is arranged so that during the damage or the short circuit would operate/wear protection and was disconnected the switch, nearest to the place of damage, and all

other parts of the installation continued normally to work. For example, if short circuit occurred at point K on diagram in Fig. 3-2, then must be disconnected switch V-1 of the waste/exiting line, and switches V-2 and V-3 of generators be disconnected must not, although in the circuits of generators will flow/occur/last the short-circuit current to the moment/torque of the cutoff/disconnection of switch V-1 of line. For this purpose relayings have special device/equipment or work with specific time element. More rapidly must operate/wear relaying, nearest to the place of the damage; for our example time element of the protection of the waste/exiting line must be less than time element of the protection of generator. Time element does not usually exceed several seconds.

Repair, cleanup, control, replacement and the like of apparatuses and machines or whole elements/cells of installation (line, power transformer, generator, etc.) must be conducted without the cutoff/disconnection of other working parts of the installation, but by the fact of an more entire installation, but with the observance of the necessary conditions of safety for those, who generate these works. The most important action, which ensures the safety of performing work in high-voltage installations, is the reliable disconnecting of the part of the installation, on which is assumed production in the works, from other parts of the installation, which are located under voltage.

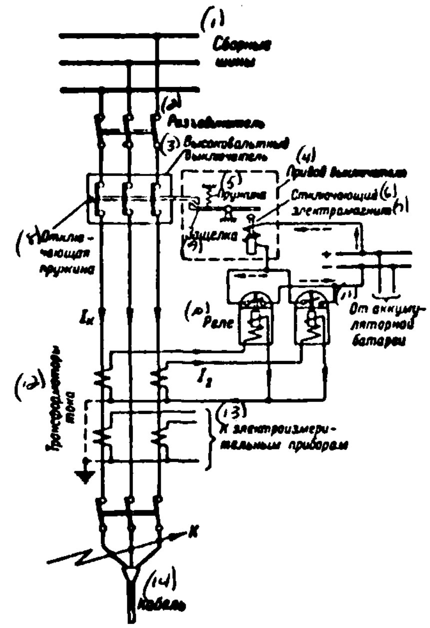

Fig. 3-3. Schematic diagram of the device/equipment of relaying of maximum current.

Key: (1). Collecting mains. (2). Disconnector. (3). High-voltage switch. (4). Drive of switch. (5). Spring. (6)-(7). Decoupling electromagnet. (8). Disconnecting spring. (9). Trip. (10). Relays. (11). From storage battery. (12). Current transformers. (13). To electric measuring instruments. (14). Cable

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In this case for warning/preventing the possible errors it is

necessary that the place of disconnecting would be performed by the apparatus, ensuring the clear visibility of the place of chain cleavage. Such apparatus is the disconnector (see Chapter 16).

As a rule, disconnectors are not intended for inclusion/connection and cutoff/disconnection of circuits, which are located under load, but serve only for inclusion/connection and disconnecting of the de-energized elements/cells installations, preliminarily off as switch. For example, if it is necessary to repair switch V-1 of the waste/exiting line, without upsetting the operation of station (Fig. 3-2), then should be disconnected first switch V-1, and then disconnectors R-2 and R-1. Then switch V-1 is disconnected from the collecting mains of station, which are located under voltage, and from the cable of line, to which can be supplied the voltage from the network/grid through any other line. In some diagrams of the electrical connections (see Fig. 3-4) disconnectors are utilized for switching of separate circuits, which are located under voltage, but when these switchings are not accompanied by the gap of power.

Disconnectors R-1, established/installed from the side of collecting mains SSh (Fig. 3-2), call busbar/tire, while disconnectors R-2 in the outputs of the waste/exiting lines - linear.

For control/checking of the work of aggregates/units and individual parts of the installation, quality of electric power (voltage and frequency) and for the account to developed and distributed electric power over electrical stations and substations are applied appropriate electric measuring instruments: ammeters, voltmeters, wattmeters, frequency meters, counters, etc.

Furthermore, are provided for the devices/equipment of automation, which ensure the automatic maintenance of the assigned mode/conditions of the work of installation (automatic field control, automatic frequency control, etc.) and which accelerate the restoration/reduction of the normal mode of work during the all possible emergencies and the disturbances/breakdowns of the mode of operation (the automatic breaking of aggregates/units, transformers, lines, etc.).

Provisions are made for also the instruments and the warning devices, which facilitate the orientation of personnel with changes in the mode/conditions of the work of equipment, and also the necessary instruments and communications.

All enumerated devices and relay are placed in the panels of the master control board or directly in the closed distributors (for greater detail, see Vol. 2).

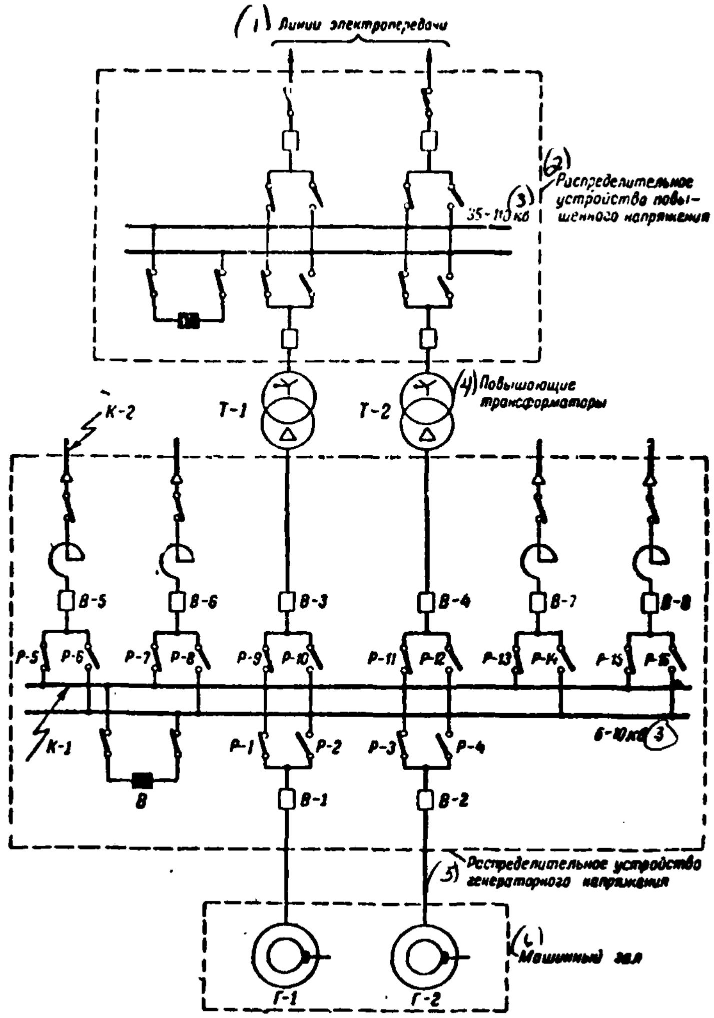

Fig. 3-4. Unilinear diagram of power plant with two systems of collecting mains at generator and increased voltages.

Key: (1). Electric power lines. (2). Distributor of increased voltage. (3). kV. (4). Step-up transformers. (5). Distributor of

generator voltage. (6). Machine room.

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In installations by voltage above 1000 V measuring meters and relay switch on through instrument transformers of current and voltage. In the diagram in Fig. 3-2 it is evident that current transformers TT are established in the circuit of each connection, and voltage transformers TN - only in the circuits of generators also on collecting mains. Before voltage transformers are connected the disconnectors and safety fuses P-1.

Collecting mains SSh and all connections between apparatuses normally make not insulated (bare) by busbars Sh on porcelain insulators. Some circuits sometimes make by cables, for example the connection of transformers T-1 and T-2 at voltage 6 kV (cables Kb).

Connections on the distributing frames by voltage to 1000 V perform by bare busbars or insulated wires.

One system of collecting mains, provided in the diagram in Fig. 3-2, does not provide the high reliability of the power supply of users, since during damage and repair of collecting mains the nourishment of users is interrupted/broken.

Fig. 3-4 gives line diagram of powerful/thick power plant during electrical power distribution at two voltages - generator and increased (in the diagram is not shown the feed of its own needs of station and are not given instrument transformers). From generators electric power comes the collecting mains of generator voltage 6-10 kV and from them partially into the network/grid of generator voltage along the waste/exiting cable lines, and partially into the step-up three-phase power transformers by secondary voltage 35-110 kV. from the latter electric power comes the collecting mains 35-110 kV and from them into the air electric power lines, employees for the feed of the distant from station users and connection/communication of station with the electric system of power system.

At generator and increased voltages are used two systems of collecting mains. Normally in work is located one set of busbars, the second set of busbars is stand-by.

The presence of two systems of collecting mains makes it possible to preserve in work installation during damage or repair of one of the systems.

During short circuit on the working system of the collecting

mains of generator voltage (at point K-1) operate/wear maximum current relayings of generators and are disconnected switches V-1 and V-2, but if station works in parallel with the network/grid of power system at voltage 35-110 kV, then are disconnected both switches V-3 and V-4. After disconnecting then the switches of all lines and transformers, they change over entire installation to the stand-by system of collecting mains, for which are disconnected all busbar/tire disconnectors of the working system of collecting mains (odd: R-1, R-3, R-5, etc.) and they connect the busbar/tire disconnectors of the stand-by system of collecting mains (even: R-2, R-4, R-6, etc.). After this are connected the generator switches, lines and transformers. Upon the start of the switches of the second and following of generators, and also upon the start of the switches of transformers, if through them is realized the multiple operation of station with power system, generators synchronize.

In two systems of collecting mains it is possible to alternately overhaul the collecting mains of station, without upsetting the operation of installation, i.e., without interrupting/breaking the nourishment of users. For example, it is required to supply on repair the working system of the collecting mains of generator voltage. For this, without interrupting/breaking operation of station, they change over installation to stand-by system of collecting mains in the following order: 1) switch on bus-connecting switch V, supplying

voltage on the stand-by system of the collecting mains; 2) switch on the disconnectors of the stand-by system of collecting mains R-2, R-4, R-6, etc.; 3) disconnect the disconnectors of the working system of collecting mains R-1, R-3, R-5, etc.; 4) disconnect bus-connecting switch V and its disconnector from the side of the working system of collecting mains.

On the waste/exiting cable lines of the generator voltage of power plant are shown the reactors (coils with considerable inductive reactance), intended for decreasing the strength of currents of short for decreasing the value of short-circuit currents in the cable system (for greater detail, see Chapter 8).

Raising transformers T-1 and T-2 usually they establish in the open air. Distributor by voltage 35-110 kV can be performed by that opened or that closed.

In other respects everything said in the relation to diagram in Fig. 3-2 is related also to the dismantled diagram.

The concept about electrical power distribution from the power plants whose diagrams were dismantled/selected above, gives the schematic unilinear diagram, given in Fig. 3-5. It is here accept that electric power partially is distributed over generator voltage

10 kV and partially at the increased voltage 35 kV. On power plant is conditionally shown one system of collecting mains both on the generator and on that increased voltages. For purposes of simplification in all circuits are not shown the disconnecting apparatuses and instrument transformers.

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The nominal voltages of electrical receivers (tubes of electric lighting - 220 or 127 V. of electric motors - 220-6000 V) usually differ from nominal voltages of the feed and distributive electric systems of high voltage, in this case of the equal to 10 and 35 kV; therefore electrical receivers are supplied from the reducing transformer substations (P-1, P-2, P-3, etc.).

Similar substations, placed near users of electric power, are intended for the feed of the appliance load of city or settlement, lighting and power loads of enterprise, etc. The substations, which feed appliance load, agricultural users, small homemade enterprises, etc., usually have only one secondary voltage it is normal 380/220 V for obtaining which on substation are installed one (substation P-1) or two (substation P-2) transformers of small power.

If substation is intended for the feed of the shop of enterprise

or small enterprise, then on it are provided for either one secondary voltage 380/220 V for feed electric lighting and electric motors (substation P-2), or two voltages (substation P-3) - one for the feed of electric lighting and the second for the feed of electric motors (0.38-6 kV). To each voltage can be established/installed one or two transformers and even it is more.

The distant from station users are supplied with more high voltage, for example 35 kV. In the diagram of Fig. 3-5 it is shown that two parallel to electric power line L-7 and L-8 supply the district (urban, industrial) reducing transformer substation P-7 to secondary voltage 10 kV, from which in turn, are supplied the reducing substations of users (P-8, P-9, P-10, etc.). From the busbars of these substations are supplied the electrical receivers (as from the busbars of substations P-1, P-2 and P-3).

The feed of the reducing substations directly from the collecting mains of stations or district substations (substations P-1, P-2, P-3, P-8, P-9) is expedient only with sufficiently powerful/thick and critical substations. Groups of small substations to usually more expediently supply from distribution points (RP), which obtain feed directly from the busbars of station or district substation. On distribution point electric power does not transform itself, since it is intended only for distributing electric power

between the separate reducing substations. From RP can be supplied the substations of urban electric system, departmental substations and even all-factory substations.

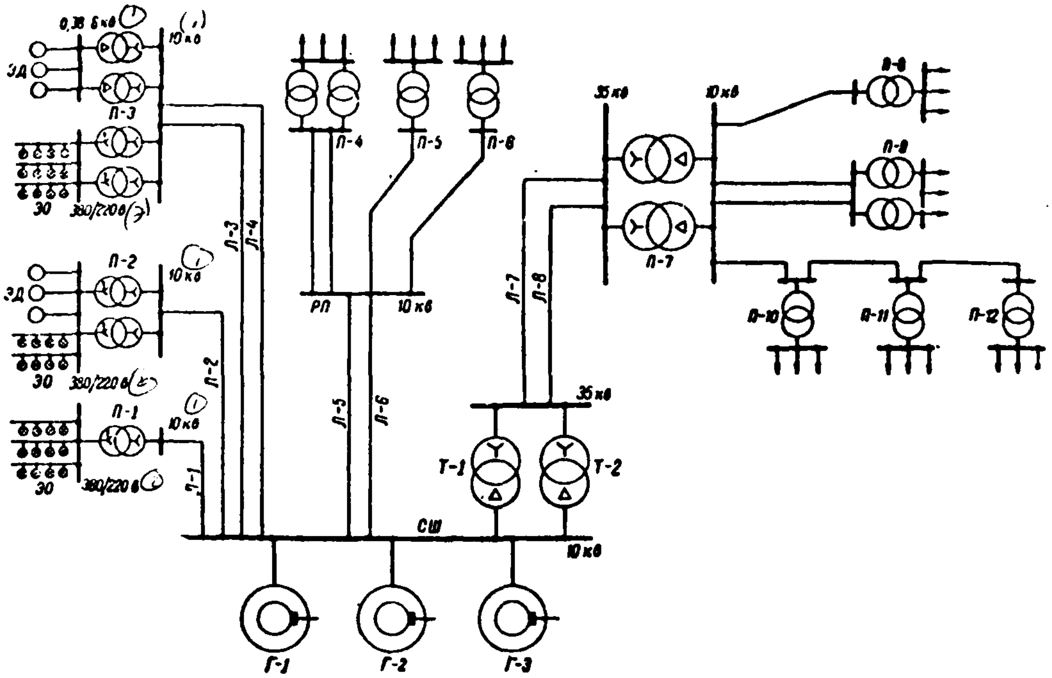

Fig. 3-5. Schematic diagram of electrical power distribution from power plant at voltages 10 and 35 kV.

Key: (1). kV. (2). V.

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Is possible the feed of several ones of substation from one line, without construction RP as this shown for substations P-10, P-11 and P-12. In both cases they decrease a number of lines, which exit from the collecting mains of station or district substation, and

initial cost of network/grid.

Substations P-10 and P-11 are passage, all others - blind, final.

The feed of substations by single lines (for example, the feed of substation P-1 by line L-1) does not provide the high reliability of power supply, since emergency to line or its cutoff/disconnection for repair they lead to the prolonged cessation of the nourishment of the users of substation. For preventing this they reserve the feed of critical and powerful/thick substations, for example, by the construction of two feeding lines: lines L-3 and L-4, feeding substation P-3, lines L-5 and L-6, feeding RP, etc. In the case of cutoff/disconnection of one of the feed lines of the corresponding substation without interruption continues along the second line.

The diagrams of the reducing substations to secondary voltage to 1000 V, for example substations P-1, P-2, P-3, etc. in Fig. 3-5, are fulfilled similarly to diagram in the part of the transformers T-1 and T-2 in Fig. 3-2.

Fig. 3-6 in the form of an example gives the unilinear diagram of district substation (P-7 in Fig. 3-5), on which are shown the switches and the disconnectors; remaining apparatuses are omitted. On

side of both voltages is accepted one system of collecting mains. On the very powerful/thick substations, which feed responsible users, are performed also two systems of collecting mains as in the diagram of Fig. 3-4 in the part of the transformers T-1 and T-2.

On the district power plants where entire/all developed by generators electric power is put out in the electric system of the increased voltage 35 kV and it is above (with exception of the small part of electric power, expended for its own needs of station), finds a use the diagram, given on Fig. 3-7. In this case of collecting mains not no generator voltage there is in view of the absence of users near station. Generators work in parallel on the collecting mains of the increased voltage. Each generator with its step-up transformer forms the integral unit, which is called "block generator - transformer".

Between the generator and the step-up transformer of no disconnecting apparatuses it is established/installed, since each of them individually work cannot. Are established/installed switches only on the side of high voltage of each block where are provided two systems of collecting mains. For the feed of its own needs of station (electric motors and illuminations) each aggregate/unit has a transformer of its own needs, connected to the busbars between the generator and the step-up transformer.

3-3. Rated currents and power of electrical equipment.

The nominal (permitted) current of electrical machines, transformers and apparatuses is called that greatest prolonged current with course of which how conveniently long time and at specific calculated ambient temperature the temperature of heating current-carrying parts and insulation does not exceed the established/installed by norms value.

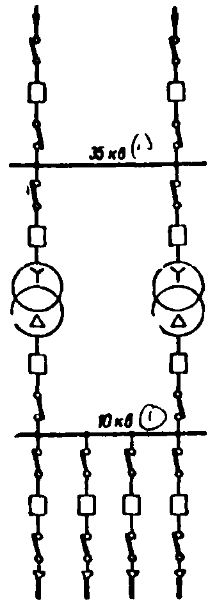

Fig. 3-6.

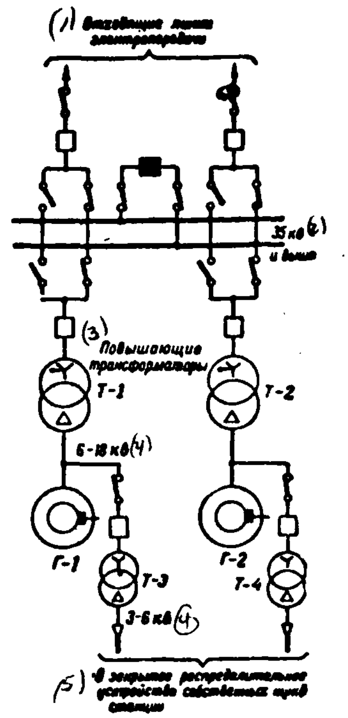

Fig. 3-7.

Fig. 3-6. the unilinear diagram of transformer substation.

Key: (1). kV.

Fig. 3-7. Unilinear diagram of district power plant.

Key: (1). Waste/exiting electric power lines. (2). kV are above. (3). Step-up transformers. (4). kV. (5). In closed distributor of its own needs of station.

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Calculated ambient temperatures at present in the USSR are as follows:

for electrical apparatuses (GOST 8024-56) and power transformers (GOST 401-41) the temperature of surrounding air ... 35°C.

for electrical machines (temperature of entering the machine air or hydrogen):

for turbogenerators (GOST 533-51) and synchronous condensers (GOST 609-54) ... 40°C.

for the hydraulic generators (GOST 5616-50) and other machines (GOST 183-55) ... 35°C.

for bare and insulated wires, busbars and power cables, laid in air ... 25°C.

for power cables in the earth/ground ... 15°C.

The long permissible temperatures of heating the parts of electrical machines, transformers and apparatuses depend on the kind

(class) of insulation, the design life (the higher the temperature of heating insulation, the less the period of its service), permissible temperature of heating contacts and they are established/installed by appropriate GOST (some of these temperatures are given subsequently in the examination of apparatuses and machines).

The established/installed by GOST 6827-54 scale of rated currents for electrical apparatuses is given in Table P-6.

For electric generators and power transformers are established/installed the specific standard values of their nominal power. With respect to this their rated currents ($I_{ном}$, A) are determined by nominal power ($S_{ном}$, kVA) with nominal voltages ($U_{ном}$, kV):

$$I_{ном} = \frac{S_{ном}}{\sqrt{3}U_{ном}}.$$

The nominal power of generators and transformers are determined under the same conditions as rated currents, i.e., at a calculated ambient temperature and a long permissible temperature of heating current-carrying parts and insulation.

The fundamental characteristics of the turbogenerators of Soviet plants are given in Table P-1, and hydraulic generators - in Table P-2. Since the resistive load of generator determines charging primary motor/engine, then given in table P-1 active power are the

nominal power of steam turbines.

In Table P-4 are given the fundamental characteristics of power transformers, while in Table P-5 - autotransformers of Soviet plants. One should remember that for transformers nominal power is the power on the terminals/grippers of secondary winding with its nominal voltage, i.e., with open-circuit voltage.

3-4. Power systems.

At present widely is realized the multiple operation of power plants on general/common/total electric system. This association of power plants is called power system (power system).

Forming part of the power system of power plant, electric power lines, substations and thermal networks/grids are connected into one whole with the generality of mode/conditions and with the continuity of the process of production and distributing electrical and thermal energy [L. 3-6].

Electrical system is called the part of the power system, which consists of generators, distributors, electrical networks and electrical receivers.

Electrical network is called the part of the electrical system, which consists of substations and electric power lines of different voltages.

Fig. 3-8 in the form of an example gives in unilinear image the part of the schematic diagram of the connections of powerful/thick power system. On all stations and substations is conditionally shown one system of collecting mains.

In power system are united the powerful/thick district of hydroelectric station S-1, two thermal district power plants S-2 and S-3 heat and power plant S-4. All stations are connected with electric system by voltage 110 kV. Electric power lines 110 kV L-2, L-3 and L-4 form the high-voltage ring; the cutoff/disconnection of any of these lines does not disrupt the connection/communication between the fundamental elements of system.

On district power plants are performed the block diagrams of connection of generators with the step-up double wound transformers; busbars not no generator voltage on these stations there is.

Hydroelectric power plant S-1 is distant up to considerable distance from the fundamental electric network of 110 kV of power system; therefore it is connected with it at voltage 220 kV with two

parallel lines L-1 through the powerful/thick substation P-1.

Station S-2 is connected directly into the ring of lines 100 kV, while S-3 station is connected to the fundamental network/grid of system by lines L-5 and L-6 through busbars of substations P-2 and P-3.

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Heat and power plant S-4 is connected to system by line L-7 through the busbars of substation P-1. Let us note that heat and power plant compulsorily they do not connect with system at voltage 110 kV. This depends on the location of heat and power central in system, amount of power, transmitted by the line of its communications with system, and distance from it to the nearest district substation. So, if heat and power plant was arranged/located nearer to district substation P-2, then it it would be possible to connect with system on any of three voltages: 110, 35 and 10 kV. In this case the rational solution can be found only via the technical-economic comparison of versions.

Substations P-1 and P-2 are the powerful/thick junction/unit substations of system. On substation P-1 are established/installed reducing triple-wound autotransformers, which have autotransformer

connection/communication between the windings 220 and 110 kV and transformer couplings between them and low-voltage winding (for greater detail, see Chapter 23). from the collecting mains 10 kV of this substation are supplied to electric consumer, arranged/located in immediate proximity of the substation: individual industrial enterprises, districts of large/coarse city, agricultural users, etc. Furthermore, at the voltage 10 kV of substation are established/installed two synchronous condensers SK, employees for mining the quadergy.

On substation P-2 are established/installed the step-down triple-wound transformers. At voltage 35 kV are supplied the sufficiently vast regions in which can be arranged/located industrial, public-service and agricultural users. At voltage 6-10 kV are supplied the users, located near substation.

Substations P-3 and P-4 are equipped by double wound transformers and can have any of the indicated in the diagram three secondary voltages.

Substation P-3 is passage, while substation P-4 - blind, final.

In the diagram 3-8 is shown only the part of the lines 220 and 110 kV of system and are in no way shown the networks/grids 35-10-6

kV, which feed from the busbars of the reducing substations and heat and power plant, or network/grid by voltage to 1000 V. The nourishment of users from the busbars 6-10 kV of substations is realized just as from the stations of the same voltage (see diagram in Fig. 3-5).

The creation of power systems has high national-economic value. First of all with joint operation on the general/common/total electric system of the series/row of power plants during the correct distribution between them of the total load of system is achieved the more economical use of equipment of separate power plants and energy resources/lifetimes of region (fuel/propellant, water energy), and also the decrease of the losses of electric power in networks/grids how is provided a decrease in the consumption of fuel, especially expensive high-energy and long-range propellants, and the considerable reduction of prices of electric power. First of all are utilized those power plants, which are equipped by the most ideal aggregates/units which work with the greatest efficiency and on cheap fuel/propellant, and also the hydroelectric power plants, which give cheapest electric power. In this case each of the stations of system covers/coats certain assigned part of the load of system.

Fig. 3-9 gives the diurnal graph/curve of the load of power system, on which is given exemplary/approximate load distribution

between the entering the system heat and power plants, district thermal and hydroelectric stations.

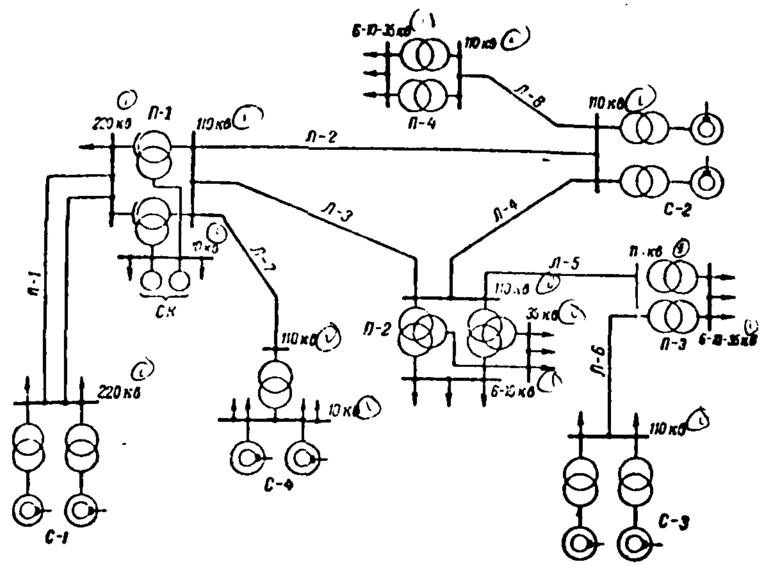

Fig. 3-8. Schematic diagram of power system.

Key: (1). kV.

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Central heating plants load, being guided by their thermal graphs/curves of loads, i.e., by a quantity of steam necessary for the heat supply of industry and cities. By this are achieved the full/total/complete guarantee of central heating users and most economical electric energy generation (see §2-2). If necessary, if the power of other stations of system in some period of time it is insufficient, heat and power plants can bear certain increment load

in condensation mode/conditions, which, however, decreases their efficiency.

The load of hydroelectric power plants determine taking into account the control of flow rivers. The remaining load of system they distribute between thermal local exchanges.

As peak stations, which work into the watches of the full loads of system (Fig. 3-9), predominantly are utilized the hydroelectric power plants, especially in the periods when they are not provided with water for a continuous operation at full power. High value have simplicity and short starting time of hydraulic generators (with the complete set of load less than 1 min). Sometimes are utilized as peak stations the thermal power plants, which work on imported fuel/propellant and least economical.

The association of power plants by multiple operation considerably increases the general/common/total reliability of the power supply of users. With emergency and cutoff/disconnection of one of the stations of system its load is redistributed between other stations of system. In this case due to charging to nominal power or even due to the small short-term overloading of the aggregates/units of the remaining in work stations is provided the uninterrupted nourishment of all or at least most responsible users of disconnected

station.

At isolated/insulated the working stations is necessary the installation of standby units, capable of replacing off aggregates/units during their damage or repair. With to the multiple operation several stations there is no necessity to establish/install standby units in each station and completely it suffices to have total for an entire system reserve capacity.

In powerful/thick power systems is possible the construction of very large/coarse power plants with the aggregates/units of the large power: 200-400 MW and even are more. Is explained this by the following reasons. For the uninterrupted power supply of users it is necessary that the system would have available a sufficient reserve capacity. They usually consider it technically sufficient and economically advisable tc have in system the reserve capacity, equal to approximately/exemplarily 10o/o of power of the aggregates/units of system. At the same time this reserve capacity must be not less than the power of the large/coarsest aggregate/unit, established/installed at the stations of system.

For example, in the power system with a power of 1000 MW, which has available reserve capacity approximately 100 MW, the installation of the aggregate/unit with a power of 200 MW requires increase in the

reserve capacity of system not less than to 200 MW, i.e., to 20o/o, that economically it cannot be justified. At the same time in the systems with a power of 2000-4000 MW and more reserve capacity is 200-400 MW and more, which makes it possible to establish/install in such systems the aggregates/units with a power of 200-400 MW and even more powerful/thick. Analogous considerations show that only in united systems of very large power it is possible to install the power plants with a power of 1000-1200 MW and more with a relatively small number of powerful/thick aggregates/units.

In the USSR there are more than 60 power systems. Largest of them are Moscow, Leningrad, Donbas, Dneprovsk, Chelyabinsk and many others [L. 3-7].

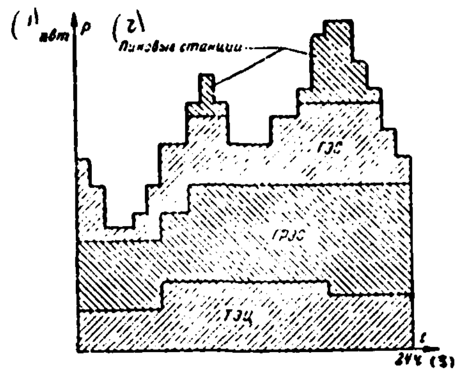

Fig. 3-9. Diurnal graph/curve of the resistive loads of power system with the indication of exemplary/approximate participation in coating of its different power plants.

Key: (1). KW. (2). Peak stations. (3). hours.

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As early as the prewar years was initiated the association of separate power systems to multiple operation. At present work the pools: Ural, which unites the Sverdlovsk, Chelyabinsk, Permian, Bashkir and Urussunsk power systems; Southern, which unites the Dneprovsk, Donbas, Rostov and Stalingrad power systems; Central, which unites Moscow, Gor'kiy, Ivanovo, Yaroslavl, Vladimir and Kalinin power systems.

The largest power plant of the country - the Volga hydroelectric power plant im. V. I. Lenin with a power of 2300 MW is connected with power transmissions by voltage 400 kV with the central and Ural pools.

Power transmission 400 kV from Volga hydroelectric power plant to Moscow with capacity to 1500 MW consists of two parallel lines long than 800 km each.

Electric power line 400 kV Volga hydroelectric power plant - Urals in 1958 is led to Chelyabinsk and there will further be continued to Sverdlovsk; the total length of this line 1050 km.

Let us note, that lines indicated above of transmission 400 kV subsequently it is planned to transfer to voltage 500 kV, that considerably will increase their capacity with small supplementary expenditures.

Thus, they already work in parallel to the power plant of the central and Ural pools and Kuybyshev power system. With this most is created the base of the single power system of the European USSR.

In 1960 the central pool will begin to obtain electric power from Stalingrad hydroelectric power plant along two lines by voltage

500 kV in long approximately 1000 km.

In 1960 must put into operation the electric power line of direct current by voltage 800 kV, length of 470 km and by the capacity 750 MW, which will connect Stalingrad hydroelectric power plant with the power system of Donbass, entering the southern integral system.

As a result of entire this, and also construction of new powerful/thick power plants and connection of other power systems, the power of the single power system of the European USSR in 1965 comprises about 50,000 MW, while in 1972 - approximately/exemplarily 72,000 MW. This there will be important in the world power combine.

Everything said earlier relative to the technical-economic value of the creation of power systems for national economy even in larger measure is related to the pools and, of course, to single power system. We will be restricted to one example. Since twilight, but respectively also evening load peaks in Urals begin on 2 h earlier than in Moscow and Donbass, then only due to this association of the power systems indicated will give decrease in the united load peak on 400-500 MW, which will make it possible to carry out the nourishment of new users without the installation of the supplementary generating power on power plants [L. 3-8].

At present Leningrad power system is connected with electric power line by voltage 110 kV with Estonian power system. On this base will be further developed the powerful/thick North Western pool.

In Caucasus Georgian power system is connected with Azerbaijan. Subsequently will be created the powerful/thick Caucasion pool into which I will enter Georgian, Azerbaijan, Armenian and Krasnodar power systems.

During the years 1960-1965 will be created the pools in Western Siberia with total installed power on the order of 8500 MW and in East Siberia - approximately/exemplarily 12,000 MW. To 1972 the power of Siberian systems will exceed 36,000 MW.

The following important stage in the development of power engineering of the USSR will be the creation of the power pool system of the Soviet Union. For this association of the European USSR with the connected to it powerful/thick North Western and Caucasion integral systems it will be connected with the system interconnection of central Siberia and the power systems of Central-Asiatic union republics. The realization of this enormous association will require the construction of the series/row of the very powerful/thick and

extended electric power lines by voltage 500 kV, and possibly, and higher voltage.

With the joint operation of power plants on general/common/total electric system is necessary the centralized management/manual of their work. This management/manual is realized by a central traffic control service of the power system in function of which enters the guarantee of fulfillment of the state plan of the power production, quality of energy, accident free and economical work of power system. For achievement this central traffic control service realizes operative management and current planning, establishes/installs the most advantageous and most reliable modes/conditions of the work of separate installations and power system as a whole.

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Operative management of the activity of entire attendant (interchangeable) personnel of power plants and supply-line regions is accomplished by the attendant dispatcher of power system, who during his duty is old operational face in power system.

Attendant dispatcher is located on the control room of power system, equipped by the dispatch board, on which are indicated all fundamental elements/cells of power system and with the aid of

special signaling is reflected their position (it is connected, disconnected, in repair, etc.). On the dispatch board are established/installed also the necessary measuring meters, which indicate loads and voltages of individual parts and installations of system. Control room is equipped also by different communications with separate stations and by supply-line regions.

The attendant dispatcher of system monitors the fulfillment by the power plants of the system of the assigned graphs/curves of loads, he follows the correctness of control of voltage and frequency, it leads by the operational actions of the attendant personnel of power plants and supply-line regions both during the normal mode of work and upon the liquidation of emergencies via the giving of indications about start and cutoff/disconnection of generators, power transformers, electric power lines, etc.

Sometimes the dispatcher can independently perform the process/operations indicated directly from control room with the aid of the special units of the control at a distance - of the so-called devices/equipment of remote control.

Remote control by fundamental objects power systems and wide automation of the production processes of hydroelectric and thermal power plants, and also electrical networks make it possible to a

considerable degree to shorten the number of personnel of all components/links of power system. Many hydroelectric stations and substations generally can successfully work without on-duty personnel.

For the management/manual of the work of the pools are created special dispatcher controls of association. The attendant dispatcher of association leads by the work of the attendant dispatchers of separate power systems in that part in which this is reflected in the work of the entire pool.

3-5. Fundamental problems of power systems, power plants and networks/grids.

The operation of all components/links of the system of production, transmission and electrical power distribution must be so it is organized so that the users would be provided in a proper quantity high-quality and possible with cheaper electric power. In accordance with these fundamental problems of power systems, power plants and networks/grids they are [L. 3-2]:

1. Fulfillment of the state plan of consumption/production/generation, transmission and energy distribution and coating the established/installed load peak.

2. Guarantee of reliable work of equipment and uninterrupted powering of users.

In general the cessation of feed by electric power of industrial enterprises can cause: 1) the underproduction of production for shutoff period: 2) the damage of raw material and unfinished production (for example, to certain chemical and metallurgical productions); 3) damage and disorder of production equipment even 4) deterioration in the sanitary-hygienic conditions of work.

If we consider entire damage, applied to production by emergencies on electrical devices, it will prove to be that for each underproduced by industry kilowatt-hour of electric power the losses of industry reach 10-15 rub and even it is more.

On electrical devices themselves some emergencies are accompanied by the damage of the most valuable equipment.

Experience of operating networks/grids, power plants and power systems as a whole shows that the emergencies appear as a result of the errors, allowed during design and mounting, the direct erroneous actions of operating personnel, and also as a result of late taking

by it of preventive actions (inspections, repairs, tests, etc.). During careful design and mounting, and also during the correctly organized operation of emergency they can be completely eliminated and electrical devices can be trouble free.

3. Maintenance of normal quality of released energy - frequency and voltage of electric current, pressure and temperature of steam and water.

The quality of electric power is determined by its voltage and frequency. Is necessary the observance of the single frequency in system and the assigned voltages in its separate parts. If the electric motors of industry are supplied by electric power of defective quality (low voltages or frequency), then the speed of their rotation becomes less than the nominal, that entails the underproduction of production, and in a number of cases the considerable overheating of engines and the decrease of the period of their service. In some enterprises can occur deterioration in the quality of production and even damage of production.

4. Achievement of greatest efficiency/cost-effectiveness of work by every possible decrease of specific expenditure of fuel/propellant for manufactured electrical and thermal energy, decreases in energy consumption for its own needs of stations, and also decrease of

losses to transmission and energy distribution.

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High va... have an increase in the use of the established/installed equipment and the careful observance of most economical modes/conditions the operations of separate aggregates/units and transmission lines. At the same time is necessary a decrease in initial initial costs of installations, but not to the detriment of the requirements of accident free and economical work.

In electrical devices very vital importance has also providing safety of work of the service personnel.

During design, installation and operation of electrical devices is to strictly fulfill all instructions of the "rules of the device/equipment of electrical installations", the "rules of the operation of electrical stations and networks/grids", "safety regulations" and other directive and instructional materials on these questions of the corresponding leading organizations the USSR.

Chapter Four.

Graphs of the loads of electrical plants.

4-1. General information.

The generators of power plants at each moment of time must develop the active and reactive power, sufficient for the nourishment of users, covering the losses in networks/grids and power transformers and of expenditure for our own needs of stations.

The necessary active power is generated by the generators of power plants due to the appropriate load of their primary motor/engines. Reactive power is generated both by the generators of stations due to their appropriate excitation and by others especially by the adjustable sources of reactive power - by the synchronous condensers or by capacitors/condensers.

Active power consume the tupes of electrical illumination, everyday and industrial heaters and some other electrical receivers; electric motors, electric induction furnaces and other similar to them electrical receivers consume both the active and reactive power.

Transmission and electrical power distribution are accompanied by the losses of active power for heating of the wires of the lines of electric systems, windings and steel of transformers. Reactive power is expended/consumed on compiling of the magnetic fields of electrical lines and in transformers.

Certain power is expended/consumed on its own needs of stations and substations: electric lighting and feed of the electric motors of mechanisms of its own needs.

The mode/conditions of the work of the users of electric power does not remain constant, but it is changed in different hours of days, days of week and months of year. Respectively changes the load of all components/links of transmission and electrical power distribution and generators of stations. As has already been indicated into §2-1, a change of the loads of electrical devices accept to depict graphically in the form of the graphs/curves of loads.

Are distinguished the graphs/curves of active and reactive load. In the first case along the axis of ordinates they plot/deposit resistive load in kilowatts (kW), and the second - reactive load in the kilo-volt-amperes of reactive/jet ones (kilovar).

By duration are distinguished the diurnal and annual graphs/curves of loads.

Diurnal graphs/curves of loads. In the form of an example Fig. 4-1 gives the diurnal graph/curve of the resistive loads of certain electrical device.

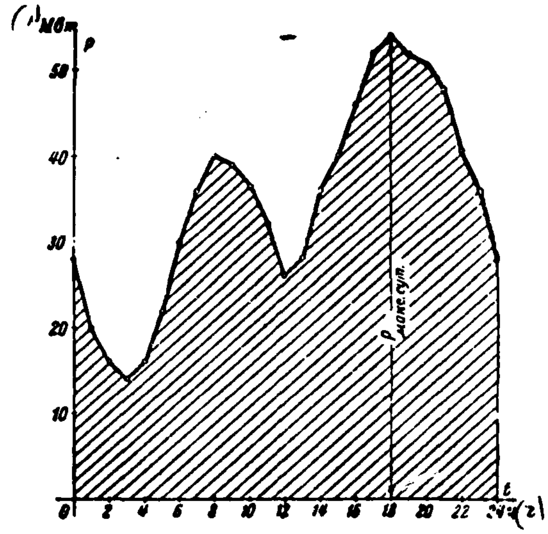

Fig. 4-1. Diurnal graph/curve of resistive loads, constructed according to points.

Key: (1). MW. (2). hours.

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The values of the resistive loads of installation at different times of days determine in projects by the appropriate calculation, and in operation - according to readings of measuring meters. The isolated points of graph/curve, which correspond to the loads indicated, connect by straight lines, why graphs/curves has the type of broken line. A similar graph/curve will be the more precisely, the less the time intervals accepted between two adjacent loads.

The area of graph/curve determines the consumption of electric power (kW•h); therefore for simplicity of computation it it is expedient to construct the graph/curve of stepped form (Fig. 4-2). With construction of stepped graph/curve take load the installations of constant/invariable in time interval between two adjacent loads. So are constructed the graphs/curves of reactive load.

For performance data of installation during year it suffices to have diurnal graphs/curves for the most characteristic days of year. For the majority of installations the most characteristic diurnal graphs/curves of loads are winter (end/lead of December) and summer (end/lead of June) diurnal grapns/curves. For some installations, connected with seasonal users (agricultural users, peateries, etc.), can be of interest also spring (March - April) and autumnal (September - October) the diurnal graphs/curves of loads. Winter graph/curve usually corresponds to the full loads of installation during year (greatest expenditure for electric lighting), and summer, on the contrary, smallest, although they can be and exception/elimination (water-pump stations, peateries, agricultural users, etc.).

The full load of installation on diurnal graph/curve (usually by

the duration not less than the half-hour) is called the maximum diurnal load $P_{макс.сут}$ (Fig. 4-1 and 4-2). The full load of this installation in the duration of year call peak load installation $P_{макс}$ (greatest ordinate of the greatest in year diurnal graph/curve, for example, winter).

The area of diurnal graph/curve (Fig. 4-2) on the specific scale gives electric power into kilowatt-hour $A_{сут}$, manufactured or consumed by this installation in the course of twenty-four hours.

Knowing $A_{сут}$, it is possible to determine the medium load of installation in days in kilowatts (Fig. 4-2):

$$P_{ср.\,сут}=\frac{A_{сут}}{24}. \qquad (4\text{-}1)$$

In practice are subdivided all numerous users of electrical stations and substations into characteristic groups, being guided by the generality of their operating mode, to the example: 1) public-service loads - habitable houses, exterior lighting, trolley and trackless trolley bus, water pipe and channeling, etc.; 2) power and lighting commercial loads with supplementary subdivision according to branches of industry, number of exchanges and the like; 3) agricultural loads (power and lighting); 4) the electrified transport, etc.

Fig. 4-3 and 4-4 give the standard diurnal graphs/curves of

loads for some groups of users, constructed on the basis of the many-year experience of operation. The ordinates of these graphs/curves are expressed in the percentages of peak load.

The character of load change from the interior lighting of the buildings of city in large degree is determined by geographic latitude (duration of the dark and light parts of the days). The diurnal graph/curve of loads from the interior lighting of the buildings of large/coarse city somewhat differs from a similar graph/curve for a small city and the more so for a settlement. Then is related also to exterior lighting.

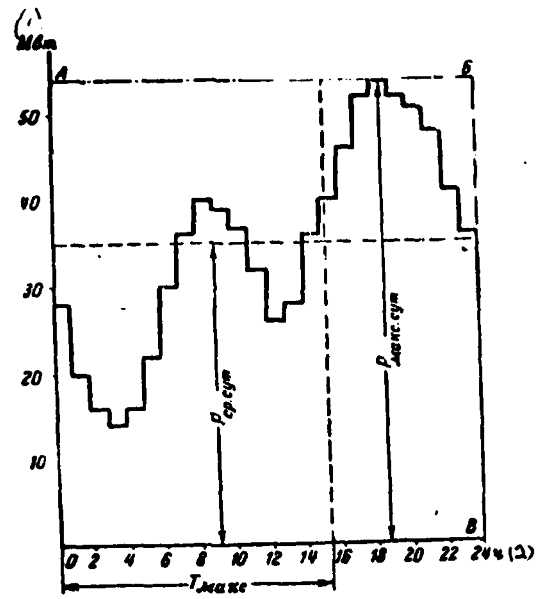

Fig. 4-2. Diurnal graph/curve of resistive loads.

Key: (1). MW. (2). hours.

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The graph/curve of loads from the electrified transport (trolley and trackless trolley bus) depends on the character of city, relief of locality (even, hilly, etc.), traffic volume on lines, etc.

The graphs/curves of the loads of industrial enterprises can considerably differ from standard depending on beginning and end/lead shifts, time of dinner breaks, value of night load, etc. Enterprises

in different fields of industry can have the differing graphs/curves of loads. For example, the graphs/curves of the loads of chemical enterprises are always more uniform in comparison with the graphs/curves of the loads of the Machine Building Plants.

Sometimes the operating time of different enterprises of artificial shift/shear for the purpose of the creation of the more uniform load of electrical stations and substations. This can lead to the fact that even for uniform enterprises, but working into different time, diurnal graphs/curves will be somewhat different.

The separately working power plants, and also the reducing substations supply certain limited circle of users. The form of the diurnal graphs/curves of similar installations depends on the composition of their users. With considerable load from electric lighting diurnal graph/curve is very nonuniform, since load into evening hours is considerably more than loads into daytime, night and morning hours (Fig. 4-5). Diurnal graph/curve in summer days sharply differs from diurnal graph/curve in winter days both value of loads into different hours and by time of peak load which is displaced by the later hours of days. Therefore the annual mode of operation of electrical station or substation, which feeds predominantly electrical illuminating users, is characterized by large nonuniformity.

With considerable power load, especially in the presence two- and three-shift/three-way interchangeable enterprises, diurnal graph/curve is more uniform (Fig. 4-6) and loads in winter days less differ from loads in the summer days (is more uniform annual mode/conditions). The more uniform the graph/curve, the more full/totaler/more complete is utilized the established/installed at station equipment and with which the large the efficiency it works (descends the prime cost of that developed of the kilowatt-hour of electric power).

Fig. 4-6 gives also the diurnal graph/curve of the reactive load of power plant. The maximums active and reactive load usually do not coincide, since during the maximum resistive load installation works with the the highest cosϕ as a result of considerable lighting load. Manifests itself also the fact that by this time conclude work the small/fine one-shift enterprises, equipped, as a rule, by small/fine electric motors with the the low cosϕ. On the other hand, into the daytime hours when lighting load is small in comparison with power, installation works with smaller cosϕ, that also gives an increase in the reactive load. Thus, reactive load changes disproportionately active as a result of inconstancy cosϕ in the course of twenty-four hours.

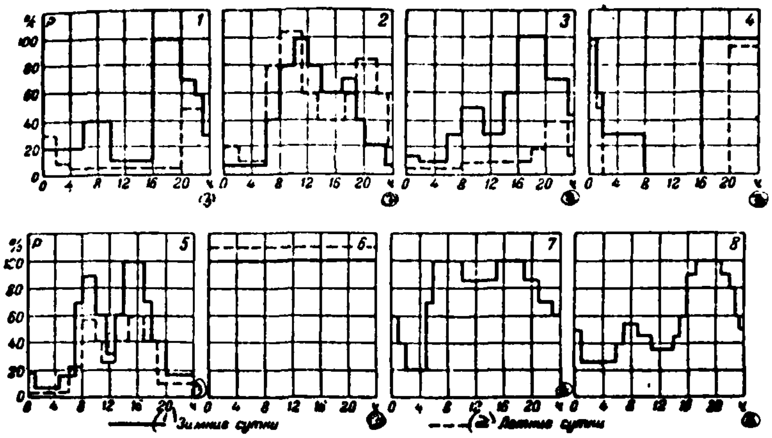

Fig. 4-3. Standard diurnal graphs/curves of the loads of the public-service of electric consumers. 1 - electric lighting of the habitable houses; 2 - small/fine domestic electric appliances; 3 - electric lighting of the public buildings; 4 - external electric lighting; 5 - everyday light power motors; 6 - the pumping stations of water pipe and channeling; 7 - urban electrified transport (trolley, trackless trolley bus); 8 - summary chart for a city with the population of 20-250 thousand inhabitants, which considers load curves by 1-7.

Key: (1). Winter days. (2). Summer days. (3). hours

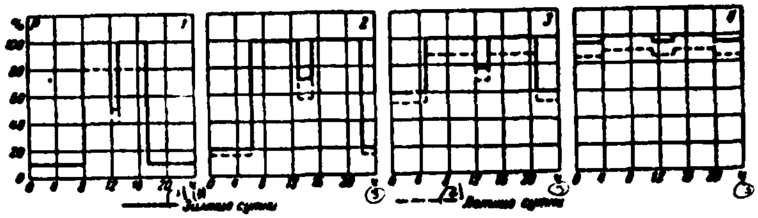

Fig. 4-4. Standard diurnal graphs/curves of the loads of industrial electric requirements. 1 - with the one-shift work; 2 - with the two-shift work; 3 and 4 - with two-and-a-half and three-shift/three-way interchangeable work.

Key: (1). Winter days. (2). Summer days. (3). hours.

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Value of cosϕ of installation depends also on charging of the electric motors of users into different hours of days, on the value of the voltage, conducted/supplied to electrical receivers and, etc. With the decrease of the load of network/grid decreases loss of voltage in it and somewhat increases the voltage, conducted/supplied to electric motors. In connection with this increases the consumed by them reactive power.

In power system all in parallel working stations participate in coating of the total load of the system (see §3-4, Fig. 3-9). Since

the networks/grids of power systems encompass very vast region and supply a large number of users with different modes/conditions works, then their diurnal graphs/curves of loads are more uniform, rather than the diurnal graphs/curves of the loads separately (it is isolated/insulated) of the working power plants. The diurnal graphs/curves of the loads of systems are similar to those given in Fig. 4-6.

Annual graphs/curves of loads. The special features/peculiarities of the annual mode/conditions of the work of electrical devices clearly are revealed/detected with the aid of the annual graphs/curves of loads. In practice they most frequently use the annual graph/curve of a change in the diurnal peak loads and annual graph/curve in duration.

The annual graph/curve of a change in the diurnal peak loads for stations with the predominant lighting load is given in Fig. 4-7. Along the axis of abscissas are deposited/postponed the days on the months of year (from 1 January through 31 December), while on axis of ordinates - diurnal load peaks. The peak load on 31 December is more than the maximum load on 1 January as a result of an increase in the load in year. The smallest diurnal peak load falls on 1 July. This graph/curve approximately can be constructed in the form of broken line as this in the form of an example shown by greasy/fatty dotted

line in Fig. 4-7.

If are known a number and the power of the established/installed aggregates/units of station or substation (generators or transformers), then, by using a similar graph/curve, it is possible to establish how many aggregates/units must be located in work in different periods of year. This makes it possible to utilize this graph/curve for the establishment of the possible periods of the repair of aggregates/units and number of aggregates/units, which can be simultaneously overhauled.

For example, let us suppose that at the station the annual graph/curve by which is given in Fig. 4-7, are established/installed four aggregates/units of the identical power, one of which is stand-by. After conducting on annual graph/curve the horizontal lines, which correspond to the power of aggregates/units, we find that for coating of maximum loads in periods from 1 January through 1 April and then from 1 October through 31 December are necessary three working aggregates/units, in periods from 1 April through 1 June and from 1 August through 1 October for coating of peak loads are necessary two aggregates/units, but in period from 1 June through 1 August - only one.

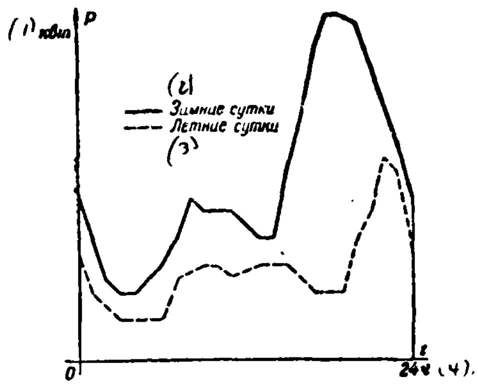
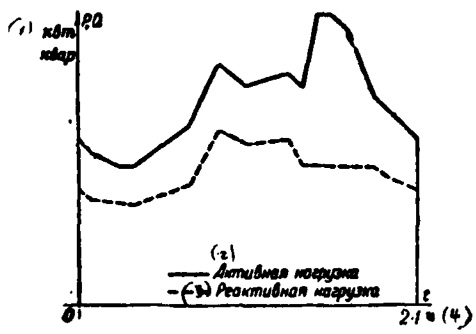


Fig. 4-5. Diurnal graphs/curves of the loads of power plant.

Key: (1). kW. (2). Winter days. (3). Summer days. (4). hours



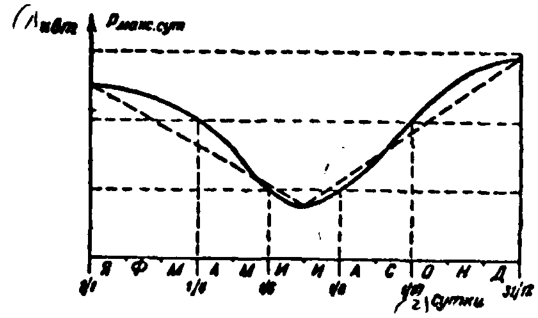


Fig. 4-6. Diurnal graphs/curves of loads of powerful/thick power plant or power system.

Key: (1). kW. kbar (2). Resistive load. (3). Reactive load. (4). hours.

Fig. 4-7. Annual graph/curve of change in diurnal peak loads.

Key: (1). kW. (2). Days.

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Using these data, establishes/installs most rational periods conducting the scheduled maintenance of the aggregates/units of station with the retenticn/preservation/maintaining of the necessary reserve capacity.

Annual graph/curve on duration is given in Fig. 4-8. This graph/curve shows duration of the work of installation during year with different loads. Along the axis of abscissas are deposited/postponed the hours of year from 0 to 8760 h, while along the axis of ordinates - load in kilowatts.

Approximately annual graph/curve on duration can be constructed on two characteristic diurnal graphs/curves of the loads of electrical device (in winter and summer days), as shown in Fig. 4-9. In this case conditionally they accept, that the duration of winter period of 213 days (7 mo.), and summer - 152 days (5 mo.).

Construction they begin with maximum and fulfill by way of a gradual decrease in the power, for which through both diurnal graphs/curves is carried out the series/row of the horizontal lines

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the distance between which select in accordance with desirable accuracy constructions.

In the form of an example let us show the determination of the annual duration of power P_1: from winter graph/curve $t_{3.1}+t'_{3.1}$, from summer - zero; annual $T_1=(t_{3.1}+t'_{3.1})213$. Plotting/depositing the obtained value of T_1 along the axis of the abscissas of annual graph/curve, we find point a. the annual duration of power P_2: on winter graph/curve $t_{3.2}+t'_{3.2}$, on summer $t_{л.2}$; is annual $T_2=(t_{3.2}+t'_{3.2})213+t_{л.2}152$. On annual graph/curve this corresponds to point b.

After fulfilling all constructions, is obtained annual graph/curve in the form of stepped broken line. It is possible to draw the curve of annual graph/curve (dotted line in Fig. 4-9), but so that the area, enclosed by this curve, would be equal to the area, limited by stepped line.

If necessary more precise constructions of annual graph/curve use a large number of diurnal graphs/curves, for example in winter, summer and spring-autumn days. In the latter case they conditionally accept the duration of winter and summer periods on 91 days, and the spring-autumn period - 183 days.

The area of annual graph/curve on the duration (it is shaded in

Fig. 4-8) on the specific scale gives electric power into kilowatt-hour $A_{год}$, manufactured or consumed by installation during year.

The average annual load of the installation

$$P_{ср.год}=\frac{A_{год}}{8760}, \qquad (4\text{-}2)$$

where 8760 - number of hours in year (24x365).

Annual graphs/curves on duration are utilized in the technical-economic calculations: with the determination of the most advantageous number and power of the aggregates/units of installation, losses of electric power in networks/grids and transformers, etc.

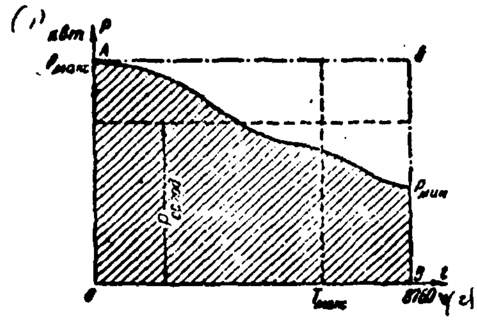

Fig. 4-8. Annual graph/curve on duration.

Key: (1). kW. (2). h.

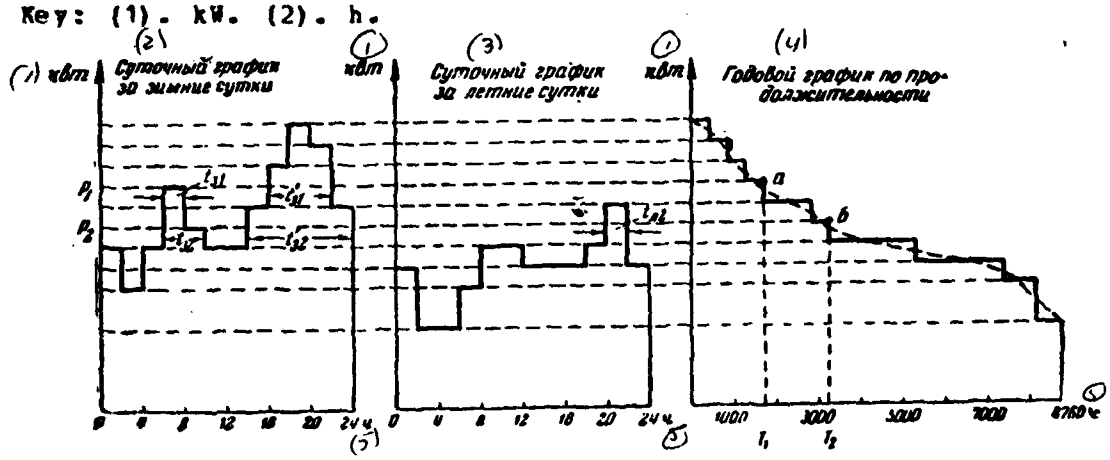

Fig. 4-9. Construction of annual graph/curve on duration.

Key: (1). kW. (2). Diurnal graph/curve in winter days. (3). Diurnal graph/curve in summer days. (4). Annual graph/curve on duration. (5). h.

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4-2. Designation of the graphs/curves of loads.

In operation on the graphs/curves of the loads:

1. Is established/installed the starting time and stop of the aggregates/units of station how are provided the steadiness of feed by electric power of users and the efficiency/cost-effectiveness of the operation of station. Since for launching/starting and connection of aggregates/units is necessary for a while, the time lag in the connection of aggregates/units with an increase in the load of station can lead to the overloading of the working aggregates/units and need of the cutoff/disconnection of the part of the users. Premature launching/starting or late cutoff/disconnection of aggregates/units leads to a decrease in the average/mean charging of aggregates/units, which can be reason for decreasing in plant efficiency, excessive fuel consumption and rise in price of electric power. Everything said to a determined degree is related to the substations on which a number of connected transformers is expedient to change with a change in the load of substation.

2. They determine, what quantity of electric power can be manufactured during days, year or other periods of operation. Knowing electric energy generation and specific fuel consumption per the manufactured kilowatt-hour, it is possible to determine the fuel consumption at station during certain period of operation (but on hydroelectric power plants according to the specific expenditure/consumption of water - expenditure/consumption of water during the specific period of time).

3. Plans/glides time conducting of repairing basic equipment.

In operation one should in every possible way approach the achievement possible of the more uniform graph/curve of the lcads of station (substation, system), thanks to which is raised the use of the established/installed equipment, decreases the specific fuel consumption and as the final result is reduced the price electric power. Very desirably also a decrease in the total load peak (without damage for the work of indiviaual users), which allows at the same installed power of station (substation, system) to ensure the nourishment of the users of larger power (connection of new users, development of those operating).

In the industrial regions of certain decrease in the total load peak and equalization of graph/curve it is possible to achieve by displacement paths of the time of the dinner breaks of shops within large/coarse enterprises (without damage for their work), establishment of the necessary hours of the work of one-shift and small/fine amateurish enterprises with the fact, in order for them to finish work before the time of load peak from illumination, so forth.

Is expedient the connection of seasonal users, who work in the periods of summer dropping of load (peatery, some agricultural users, etc.), and also users, who have light load during the load peak of station (substation, system).

During design on curves of loads is determined the peak load of station or substation. Knowing the latter, and also character load changes during characteristic days and only year, select a most economical and convenient in operation number of aggregates/units and their power.

The graphs/curves of loads use also with the computation of the losses of electric power in electric power lines and power transformers, during the determination of most economical mode/conditions the works of the aggregates/units of stations or transformers of substations, also, for some other purposes.

4-3. Coefficients, which characterize the mode/conditions of the work of electrical plants.

Mode/conditions the work of electrical devices during certain period of time (days, year) are characterized by the following values.

Degree of irregularity (filling) of the graph/curve of the loads of installation characterizes load factor (duty factor of graph/curve)

$$k_{н}=\frac{A}{TP_{макс}}=\frac{P_{ср}}{P_{макс}}, \qquad (4\text{-}3)$$

where T - a number of hours of the work of installation during the period of time (in days T=24 h; in year T=8760 h)in question; A - manufactured or consumed quantity of electric power for the same time; $P_{ср}$ - mean load of installation for the same time; $P_{макс}$ - the peak load of installation for the same time (days, year).

They distinguish $k_{н.сут}$ and $k_{н.год}$. When $k_{н}=1$ (great possible value) the graph/curve is converted into straight line, parallel to the axis of abscissas (line dotted line with point in Fig. 4-2 and 4-8).

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Factor of load $k_{н}$ shows how many times the manufactured (consumed) quantity of electric power during the period of time (days, year) in question less than that quantity of electric power which would be manufacture/ (it is consumed) within the same time, if the load of installation always was equal to maximum, i.e., $P_{макс}$ ($k_{н}$ it was equal to the ratio of the area of graph/curve, equal to A, to the area of rectangle OABV, equal to $P_{макс}T$ - see Fig. 4-2 and 4-8). Comparing $k_{н}$ for different installations (calculated during the identical period of time), it is possible to establish/install, which of them works with more uniform graph/curve, since the more uniform the graph/curve, nearer $k_{н}$ to one.

For the characteristic of the graph/curve of the loads of installation it is possible to use also the demand time of the peak load

$$T_{макс}=\frac{A}{P_{макс}}, \qquad (4\text{-}4)$$

which shows, how many hours during the period of time (days, year) in question installation must work with constant/invariable peak load in order to manufacture (to consume) that actually/really manufactured (consumed) during this period of time a quantity of electric power ($T_{макс}$ it is equal to the base of the rectangle with a height of

$P_{\text{макс}}$, whose area was equal to A, i.e., the area of real curve of loads, see Fig. 4-2 and 4-8).

It is obvious that $T_{\text{макс}} < T$. Comparing formulas (4-3) and (4-4), we find:

$$A = k_{н} T P_{\text{макс}} = T_{\text{макс}} P_{\text{макс}}, \qquad (4\text{-}5)$$

whence

$$T_{\text{макс}} = k_{н} T. \qquad (4\text{-}6)$$

In practice they use also the capacity factor

$$k_{в} = \frac{A}{T P_{\text{уст}}} = \frac{P_{\text{ср}}}{P_{\text{уст}}} \qquad (4\text{-}7)$$

or the demand time of the installed power

$$T_{\text{уст}} = \frac{A}{P_{\text{уст}}} = k_{и} T. \qquad (4\text{-}8)$$

In formulas (4-7) and (4.8) by $P_{\text{уст}}$ should be understood the total installed power in the kilowatts of all aggregates/units, including stand-by ones.

The coefficient of use $k_{и}$ characterizes the degree of utilization of installed power of aggregates/units (use of equipment). It is obvious that $k_{и} < 1$ and $k_{и} < k_{н}$. When $k_{и} = k_{н}$ on station or substation there is no reserve capacity of generators or

transformers.

The demand time of installed power shows, how many hours during the period of time in question must be to work all established/installed at station generators (on substation - transformers) with full load, in order to manufacture the actually/really manufactured for the time indicated quantity of electric power A. As a rule $T_{уст} < T$.

The annual demand time of peak load $T_{макс}$ of power stations and substations depends from the character of their load and comprises to 2000-4000 h ($k_{н}$ =0,23—0,45) for installations with considerable lighting load and for isolated/insulated the working stations and to 4000-7000 h ($k_{н}$ =0,45—0,80) for the powerful/thick installations, which feed predominantly power load, moreover more than numeral they are related to the power systems, which feed the heavy industry, which works in three exchanges.

4-4. Construction of the diurnal graphs/curves of loads in operation.

The diurnal graphs/curves of loads, which are found in the exploitation of users, can be constructed by measuring the required by them power.

The graphs/curves of resistive loads can be constructed from readings of the wattmeters, adjusted in a number of cases on lines or substations, which feed the powerful/thick consumers. For this reading of wattmeters they write/record through the specific time intervals - in 1 h or 30 min - depending on the desirable degree of accuracy of graphing. In the absence of the constantly connected wattmeters are utilized movable wattmeters.

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The graphs/curves of reactive load can be constructed from readings of the ampere-voltmeters of reactive/jet ones. In the absence of the latter are utilized the ammeters, the voltmeters and the wattmeters from readings of which are determined first factor of the power

$$\cos\varphi = \frac{P}{\sqrt{3}UI},$$

and then the reactive load

$$Q = P\,\mathrm{tg}\,\varphi. \qquad (4\text{-}9)$$

Value of tgφ is found through trigonometric tables in the known value cosφ. In some cases are used phasemeters, which directly measure cosφ.

It is very simple to construct the diurnal graphs/curves of users from the counter readouts of energy, established/installed for calculation for electric power with the feeding system. By counter is determined the average/mean value of the required power from any desirable degree of accuracy, i.e., in any time interval.

For example, if counter readout are written/recorded in the hour, moreover two subsequent readings are equal to A_1 and A_2, then the medium load of user in given hour will compose $A_2-A_1/1$ kW. If recording is conducted through each of half-hour, then medium load will compose $(A_2-A_1)/1/2$ kW. Having a recording of counter readouts in days, it is possible to construct the diurnal graph/curve of the loads of user (stepped, in terms of the average/mean values of loads).

Analogously from the counter readouts of quadergy it is possible to construct the diurnal graph/curve of the reactive load of user.

The diurnal graphs/curves of the resistive loads of power plants and substations construct on the basis of hour (or half-hour) recordings of readings of wattmeters, established/installed on generators or transformers. On small substations in the absence of the wattmeters of the graph/curve of loads it is possible to construct from readings of counters established/installed to

transformers.

The diurnal graphs/curves of the reactive load of generators are constructed from readings of the established/installed on them ampere-voltmeters of reactive/jet ones, but in their absence are utilized readings of their ammeters, voltmeters and wattmeters as this shown above.

If on generators are established/installed the recording (recording) wattmeters and ampere-voltmeters reactive/jet, then the graphs/curves of the loads of aggregates/units are obtained directly on the tapes of these instruments. Summarizing the diurnal recordings of recorders of all aggregates/units, is obtained the diurnal graph/curve of an entire installation. At powerful stations with several installations are installed also adding recording devices; the total curve of the load of the station is recorded on the tape of this instrument.

4-5. Construction during the design of the diurnal graphs/curves of the loads of users and substations.

For the construction of the diurnal graph/curve of the loads of substation it is necessary to have the diurnal graphs/curves of the loads of consumers supplied from this substation.

Let us begin with the examination of the simplest case of the construction of the diurnal graph/curve of the loads of substation to secondary voltage of up to 1000 V, which feeds the group monotypic electric receivers with the same operating modes (for example, substations P-1 in Fig. 3-5). For this, first of all, necessary to know total established/installed $P_{y\Sigma}$ and total that connected $P_{np\Sigma}$ powers of the electric receivers.

Under the installed power of electrical receiver is understood its power on certificate, i.e., its nominal power $P_{ном}$. In particular established/installed, i.e., by nominal, power of electric motor is the power, developed with it on shaft with full load. Thus $P_{y\Sigma}=P_{ном\Sigma}$ it is defined as the sum of the nominal (certified/rating) power of all electrical receivers, established/installed in the network of substation.

By the connected power of electrical receiver is understood the power, consumed by it from network during full/total/complete charging. For the incandescent bulbs, heaters and furnaces $P_{np}=P_{y}=P_{ном}$, while for electric motors $P_{np}=\frac{P_y}{\eta_д}=\frac{P_{ном}}{\eta_д}$, where $\eta_д$ - efficiency of electric motor during full/total/complete (nominal) charging.

Thus, $P_{np\Sigma}$ is defined as the total power, consumed from network

by all electricity receivers when they all are connected to network and work with full/total/complete charging. Approximately for the group of electric motors $P_{npz}=\frac{P_{yz}}{\eta_{\partial}}$, where η_{∂} - average/mean value the efficiency of electric motors.

Consumed from network by the group of electrical receivers power or, in other words, net load P_{μ} at any moment of the time, is always less than the total connected power of electrical receivers and is only in rare cases equal to it ($P_{\mu}\leqslant P_{npz}$).

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Is explained this, first of all, by the fact that to electric system usually are connected not all established/installed electrical receivers, but sometimes also by the fact that not all connected receivers work with full load.

If we take for an example the internal electric lighting of habitable houses, then never it is so that would be simultaneously connected all tubes of the interior lighting even of one large/coarse habitable house, but that it is more district of city, whole city, settlement, etc. Even into the evening hours of winter days some part of the tubes remains off.

In the major industrial enterprise, equipped by a large number of electric motors, also never it is so that simultaneously would work all established/installed electric motors, that as part of the production mechanisms usually is located in leading-in or repair, many auxiliary mechanisms work periodically (taps/cranes, hoists, compressors and many others), in complicated mechanisms with co-ordinated drive the electric motors work in the specific sequence in proportion to the fulfillment of separate process/operations, etc.

Production mechanisms and machine tools supply with the standard electric motors whose nominal power sometimes somewhat exceeds the required power of mechanism or machine tool, determined from the conditions for their greatest charging. However, the real charging of mechanism or machine tool is determined by the conditions for technological process and can considerably differ from calculation. Therefore some electric motors of enterprise work with fractional load.

The greatest in year power, consumed by electrical receivers during not less than the half-hour, it is called peak load $P_{н.макс}$ and it is determined from the condition:

$$P_{н.макс} = k_o k_з P_{пр}, \quad (4\text{-}10)$$

where k_o - a diversity factor of the work of the electrical

receivers; $k_з$ - load factor of electrical receivers.

Diversity factor $k_о$ shows, what part of the connected power of all established/installed electrical receivers composes the connected power of the receivers, which work during peak load, i.e.

$$k_о = \frac{P_{пр.раб}}{P_{пр\Sigma}}, \qquad (4\text{-}11)$$

where $P_{пр.раб}$ - the connected power of the electrical receivers, which work during the peak load; $P_{пр\Sigma}$ - total connected power of all electrical receivers.

Load factor $k_з$ characterizes charging the electrical receivers, which work during peak load. In other words, load factor shows, what part of the connected power of the electrical receivers, which work during maximum composes their peak load, i.e.

$$k_з = \frac{P_{н.макс}}{P_{пр.раб}}. \qquad (4\text{-}12)$$

Coefficients $k_о$ and $k_з$ can be equal or less than unity in dependence on type and number of electrical receivers and mode of their operation.

In the form of an example let us point out that according to the data of operation the diversity factors of installations of internal electric lighting in small cities and settlements compose 0.7-0.8,

and in large/coarse cities 0.4-0.7, the interior lighting of industrial enterprises 0.6-0.8, external electric lighting 1. Load factor of electrical illuminating installations in all cases $k_{з}=1$.

For obtaining the diurnal graph/curve of the loads of substation it is necessary to first construct the diurnal graph/curve of the loads of electrical receivers, which feed from this substation. in this case they use the appropriate standard diurnal graph/curve or the diurnal graph/curve of the analogous operating user, introducing into it the necessary changes in the relation to the time of beginning and termination of shifts, the duration of shifts and dinner breaks and other individual characteristics of users.

The materials, necessary for graphing of the loads of users, are given in the appropriate management/manuals and manuals [4-1].

After accepting for base certain diurnal graph/curve and having previously calculated value $P_{н.макс}$, it is easy to determine load in kilowatts for each hour of days and to construct in the corresponding scale the diurnal graph/curve of the loads of user.

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The graph/curve of the loads of substation differs from the use

conditions by the magnitude of losses of power in network. Losses in the wires of network are the losses by variable/alternating ($P_{пер}$), since it are directly proportional to square the load of network.

After constructing in the coordinate axes the diurnal use conditions, add to its ordinates variable/alternating losses into the networks (Fig. 4-10), calculated as follows.

Variable/alternating losses in network with peak load are determined from the formula:

$$P_{макс.пер}=\frac{p_{пер}\%}{100}P_{н.макс}, \qquad (4\text{-}13)$$

where $p_{пер}\%$ - losses in the wires of network in percentages of $P_{н.макс}$.

Variable/alternating losses in any hour of days t with load P_t, (Fig. 4-10)

$$P_{пер\,t}=P_{макс.пер}\frac{P_t^2}{P_{н.макс}^2}. \qquad (4\text{-}14)$$

In networks by voltage of up to 1000V $p_{пер}=$ 3-5o/o.

The peak load of substation can be determined without graphing of load by the formula:

$$P_{макс.подст}=P_{н.макс}+P_{макс.пер}.$$

Taking into account formulas (4-10) and (4-13), it is possible to write:

$$P_{\text{макс.подст}} = \left(1 + \frac{p_{\text{пер}}\%}{100}\right) k_o k_з P_{\text{пр}\Sigma} = \left(1 + \frac{p_{\text{пер}}\%}{100}\right) k_o k_з \frac{P_{\text{у}\Sigma}}{\eta_{\text{д}}},$$

or

$$P_{\text{макс.подст}} = k_c P_{\text{у}\Sigma}, \qquad (4\text{-}15)$$

where

$$k_c = \left(1 + \frac{p_{\text{пер}}\%}{100}\right) \frac{k_o k_з}{\eta_{\text{д}}}$$

- the coefficient of the demand of the group of electrical receivers, which considers both the diversity factors and charging of receivers and their efficiency and loss in network from receivers to the transformers of substation [4-1].

If substation supplies several groups of users with different operating modes, then for each characteristic group of consumers they determine $P_{\text{у}\Sigma}$ and $P_{\text{пр}\Sigma}$, accept the values of coefficients k_o and $k_з$, compute $P_{\text{н.макс}}$ and are constructed the diurnal characteristic graphs/curves of loads. For graphing of the loads of substation are constructed the characteristic graphs/curves of all groups of users into some coordinate axes (on one scale, also, for one and the same days) and, summarizing their ordinates, obtain total graph/curve

consumptions (Fig. 4-11). This construction is produced for all characteristic days. Further construction let us examine in connection with winter days, i.e., to the period of the full load of installation.

In general the maximum of the total use conditions can be equal or less than the sum of the maximums of the individual users

$$P_{\text{макс.сум}} \leq \Sigma P_{\text{н.макс}}.$$

The participation of individual users in the formation/education of the maximum of total graph/curve characterize by the coefficient of participation in maximum $k_{\text{уч}}$, equal to relation the values of the load of this user, which participates in formation/education $P_{\text{макс.сум}}$, to his maximum.

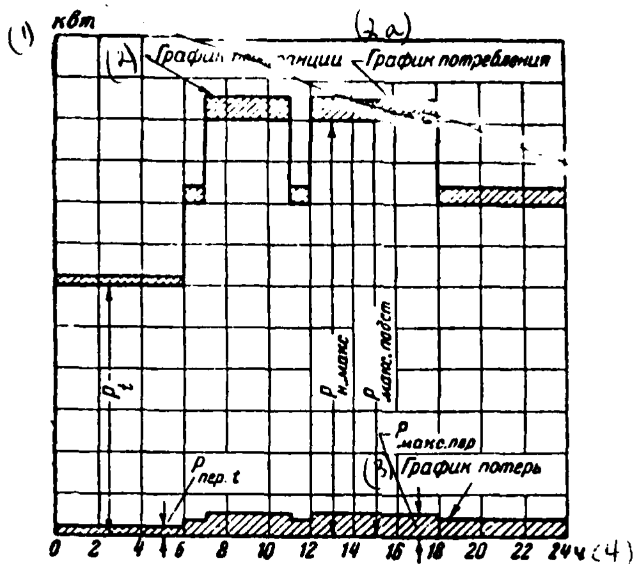

Fig. 11. Fig. 4-10. Construction of diurnal graph/curve of loads of substation, which feeds group of uniform electrical receivers.

Key: (1). kW. (2). Graph/curve of substation. (2a). Use conditions. (3). Graph/curve of losses. (4). h.

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For example, for user 2 (Fig. 4-11) $k_{уч2}=\frac{P_2}{P_{н.макс2}}$, and for a user 1 coefficient $k_{уч1}=1$.

For users, who do not participate in formation/education

$P_{\text{макс сум}}$, value $k_{уч}=0$. It is obvious that the users with low value $k_{уч}$ improve the graph/curve of the loads of substation, and thereby also the power plant.

To the obtained total use conditions is added the power of losses in network, as noted above, and are obtained the graph/curve of the loads of substation and its peak load $P_{\text{макс.подст}}$.

If are known the coefficients of participation in load peak of the separate groups of users, then without graphing of loads the peak load of substation can be determined by the formula:

$$P_{\text{макс.подст}}=\left(1+\frac{p_{\text{пер}}\%}{100}\right)(k_{уч1}P_{\text{н.макс}1}+ \\ +k_{уч2}P_{\text{н.макс}2}+k_{уч3}P_{\text{н.макс}3}+\dots)= \\ =\left(1+\frac{p_{\text{пер}}\%}{100}\right)P_{\text{макс.сум}}, \quad (4\text{-}16)$$

where $p_{\text{пер}}\%$ - losses in network in percentages of $P_{\text{макс.сум}}$.

With the known coefficients of demand [see formula (4-15)] for each group of users the same peak load of substation can be determined and thus:

$$P_{\text{макс.подст}}=k_{уч1}k_{c1}P_{у\Sigma1}+k_{уч2}k_{c2}P_{у\Sigma2}+ \\ +k_{уч3}k_{c3}P_{у\Sigma3}. \quad (4\text{-}17)$$

In practice they frequently use the values of the coefficients of demand, determined taking into account the participation of the

groups of users in the formation/education of the load peak of substation. Then calculation even more is simplified: into formula (4-17) for each group of users introduce the coefficient of demand, in reference to the busbars of the feeding substation and to time its peak loads [4-1].

Analogously is determined the peak load of substations with secondary voltage above 1000V (for example, the district substation P-7 in Fig. 3-5). In this case the coefficients of demand must be related to the secondary high-voltage busbars of substation, i.e., they must be determined taking into account power losses in the networks of all voltages from the terminals/grippers of electrical receivers to the busbars of the secondary voltage of this substation, including coil losses and steel of the step-down transformers substations in users (P-8, P-9, P-10, P-11 and P-12 in Fig. 3-5).

If it is necessary to construct the diurnal graph/curve of the loads of a similar substation, then they enter the same, as it was stated in the relation to graphing of loads in Fig. 4-11, but only are considered power losses in the wires of networks do and above 1000V and in the transformers of the secondary substations, which feed from that projected/designed.

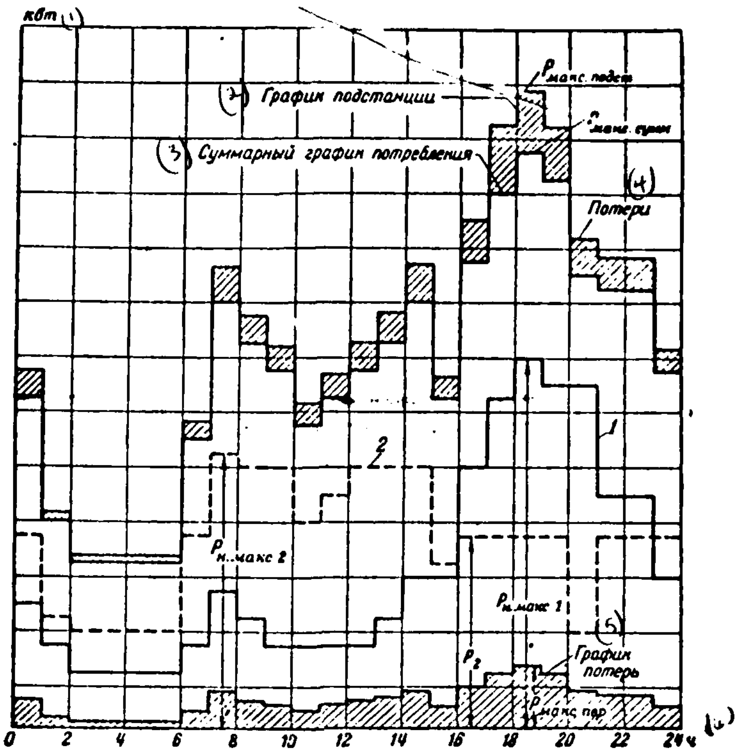

Fig. 4-11. Construction of the diurnal graph/curve of the substation, which feeds two groups of electrical receivers with different operating mode.

Key: (1). kW. (2). Graph/curve of substation. (3). Total graph/curve of consumption. (4). Losses. (5). Graph/curve of losses. (6). hour

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Losses in the wires of networks by voltage of up to 1000V, and also the losses in networks by voltage are above 1000V taking into account coil losses (copper) of transformers can be taken as equal ones (in percentages of the maximum of total consumption):

(1) в сетях напряжением до 1 000 в . . 3—5%
(2) в промышленных сетях напряжением выше 1 000 в . . . . 6—8%
(3) в коммунальных сетях напряжением выше 1 000 в . . . 8—10%
(5) в электрических системах . . (6) до 14—18%
(4) от $P_{макс.сум.}$

Key: (1). in networks by voltage of up to 1000V. (2). in industrial networks by voltage it is above 1000V. (3). in public-service networks by voltage it is above 1000V. (4). from. (5). In power systems. (6). to.

Losses in steel of the transformers:

(1) в коммунальных и промышленных сетях напряжением выше 1 000 в . . 1—1,5%
(3) в электрических системах . . . . 2—3%
(2) от $P_{макс.сум}$

Key: (1). in public-service and industrial networks. (2). from. (3). in power systems.

Losses in the wires of networks and the windings of transformers are the losses by variable/alternating ($p_{пер}$ %) and they are computed, as noted above.

Losses in steel of transformers do not depend on their load, i.e., they are the losses by constants ($p_{пост}$ %).

In the course of twenty-four hours the total quantity of losses in steel of transformers in network can somewhat change as a result of cutoff/disconnection and start of the part of power transformers on substations with the appropriate change in their load. However, with graphing this they do not consider and accept losses in steel of transformers constant/invariable ones.

Power damping constant

$$P_{пост} = \frac{p_{пост}\%}{100} P_{макс. сум}, \qquad (4\text{-}18)$$

Adding the power of variable/alternating and damping constant to the ordinates of the conditions of total use, obtains the graph/curve of substation and its peak load. Usually the peak load of similar substations is somewhat less than the sum of the peak loads of secondary substations as a result of their noncoincidence on time.

A quantity of electric power, expended in year by user, can be determined by the following formulas:

$$A_{год} = P_{н.макс} T_{макс} \qquad (4\text{-}19)$$

or

$$A_{год} = P_{ср} T_{ср}, \qquad (4\text{-}20)$$

where $T_{макс}$ - demand time of load peak (see §4-3);

$T_{пр}$ - demand time of the connected power of electrical receivers.

The demand time of the connected power of electrical receivers shows, how many hours in year receivers must work with full/total/complete charging in order to consume the actually/really spent by them in year quantity of electric power. It is obvious that $T_{пр}<8760$ h.

Are given below values $T_{макс}$ for some groups of the users:

(1) Внутреннее электроосвещение	1 500—2 500 ч (2)
(3) Наружное "	2 500—3 000 ч (2)
(4) Односменные промышленные предприятия	2 000—2 500 ч (2)
(5) Двухсменные " "	4 000—5 000 ч (2)
(6) Трехсменные " "	5 000—7 000 ч (2)

Key: (1). Internal electric lighting. (2). h. (3). External. (4). One-shift industrial enterprises. (5). Two-shift. (6). Three-shift/three-way interchangeable.

4-6. Construction during the design of the diurnal graphs/curves of the loads of power plants.

The diurnal graphs/curves of the loads isolated/insulated of the working power plants construct just as the graphs/curves of the loads of substations. Difference consists in the fact that after is constructed the total use conditions and are taken into consideration losses in networks and transformers, obtain graph/curve temperings from the busbars of station. For obtaining the final graph/curve of the loads of station, i.e., the graph/curve of the loads of its machines, it is necessary to the graph/curve of tempering from the busbars of station to add the power, expended for its own needs.

Maximum power consumption per its own needs of power plants in percentages of the installed power of station comprises approximately/exemplarily:

(1) Электростанции на жидком топливе (мазут, нефть) и газе	3—5%
(2) Электростанции небольшой мощности на угле, сжигаемом в кусковом виде (на цепных решетках)	5—7%
(3) Конденсационные паротурбинные электростанции на пылеугольном топливе	6—9%
(4) Теплоэлектроцентрали на пылеугольном топливе	8—14%
(5) Гидроэлектростанции средней мощности . .	1—2%
(6) Гидроэлектростанции большой мощности . .	0,4—1%

Key: (1). Power plants on liquid propellant (petroleum residue, oil) and gas. (2). Power plant of small power at angle, burned in cake form (on chain grates). (3). Condensation steam-turbine power plants on pulverized coal fuel/propellant. (4). Thermoelectric centers on pulverized coal fuel/propellant. (5). Hydroelectric power plants of average/mean power. (6). Hydroelectric power plants of large power.

The power, expended for its own needs of power plant, depends on type and power of power plant, and for steam-turbine power plants - also from the kind of the fuel/propellant of the method of its combustion and parameters of steam.

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If the load of the aggregates/units of station is sufficiently permanent, then with graphing of the load of station it is possible approximately to accept that the power consumption per its own needs remains always constant/invariable and equal to

$$P_{с.н} \approx P_{макс.с.н} = \frac{P_{с.н}\%}{100} P_{уст}, \qquad (4\text{-}21)$$

where $P_{уст}$ - the installed power of the generators of station, kW.

During the considerable load variations of station it is possible to approximately consider that approximately/exemplarily 40o/o of maximum power consumption per their own needs ($P_{макс.с.н}$) do not depend on the load of the station (power, consumed by the constantly working mechanisms of our own needs, part of the constantly connected illumination, the power, expended to covering of no-load losses in the electric motors of its own needs and, etc.),

and 60% $P_{\text{макс.с.н}}$ changes the proportionally resistive load of station.

This graphing of power consumption per its own needs of station is carried out in Fig. 4-12; there is constructed the graph/curve of the loads of station (graph/curve of consumption/production/generation). On diurnal graph/curve the consumptions/productions/generations in winter days determine the peak load of station $P_{\text{макс}}$.

If necessary the diurnal graph/curve of the reactive load of power plant can be constructed as follows. Having available the diurnal graph/curve of the resistive loads of the user and knowing cosϕ, with whom it works, is determined reactive load into different hours of the day. In terms of the obtained values is constructed the diurnal graph/curve of the reactive load of user. With the preliminary graphing of reactive load usually is not considered change cosϕ in the course of twenty-four hours and they take as its constant and equal to 0.9-0.95, assuming that in enterprises are accepted the measures for increase cosϕ to the value indicated.

Summarizing the graphs/curves of the reactive load of users and taking into account the expenditure/consumption of reactive power in networks and transformers, is obtained the graph/curve of the

reactive load of station.

The graphs/curves of the loads of the power plants, which work to the general/common/total electric system of power system, are assigned to power plants by the supervisory control of power system. The latter, as noted in Chapter 3, determines the load of each power plant of power system on the basis of the conditions of providing the reliable feed with power consumers and understanding of the most economical mode of operation of power system as a whole.

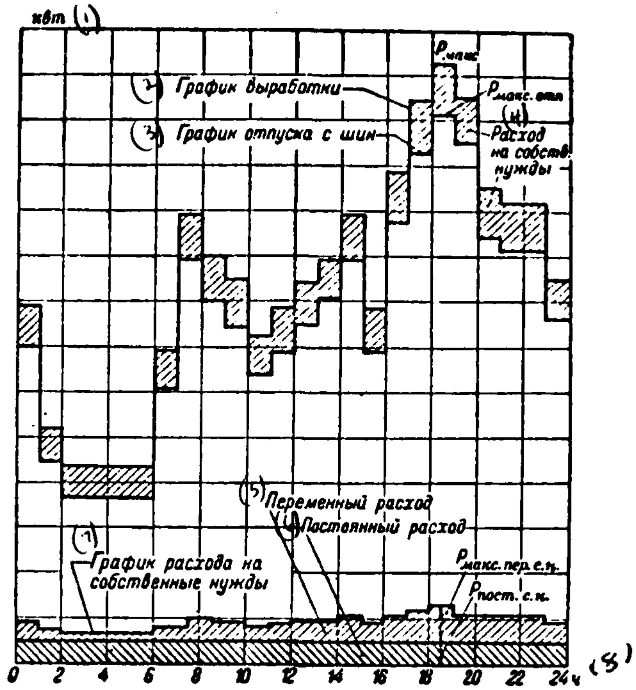

Fig. 4-12. Construction of the diurnal graph/curve of the loads of power plant.

Key: (1) kW. (2) Curve of generation. (3). graph/curve of tempering from busbars. (4). Expenditure for its own needs. (5). Variable/alternating expenditure/consumption. (6). Permanent flow rate/consumption. (7). Graph/curve of expenditure for its own needs. (8). hour.

Chapter Five.

THREE-PHASE NETWORKS WITH UNGROUNDED AND GROUNDED NEUTRALS.

5-1. three-phase networks with the ungrounded neutrals.

Each phase of network possesses relative to the earth/ground certain capacity/capacitance, evenly distributed along the length of wires. For simplification in further reasonings we count the three-phase network of symmetrical and uniformly distributed capacitances of phases relative to the earth/ground we conditionally replace by capacities/capacitances C, concentrated on the middle of line (Fig. 5-1).

Interphase capacities/capacitances and caused by them permittance currents we do not consider, since, as this will be shown below, during single-phase closings/shortings to the earth interphase voltages do not change, and consequently, do not change the permittance currents, caused by interphase capacities/capacitances.

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In the normal mode of the work of the voltage of the phases of

network relative to earth/ground $\dot{U}_A, \dot{U}_B$ and $\dot{U}_C$ are symmetrical and numerically equal to the phase voltage of installation, but currents in the phases of source - to vector sum of the currents of leads $I_{н.A}, I_{н.B}, I_{н.C}$ and capacitive (charge) currents of phases relative to earth/ground I_{C_0} (Fig. 5-1a and b). Vector sum of the permittance currents of three phases is equal to zero (Fig. 5-1c); therefore no terrestrial current it flows/occurs/lasts.

In the case of damage to insulation and closing/shorting to the earth of one of the phases the voltages of phases with respect to the earth/ground change (Fig. 5-2), in consequence of which change the values of the permittance currents in network, caused by the capacity/capacitance of the phases of network with respect to the earth/ground. With full/total/complete (metallic, dead/blind) shorting of phase to the earth the voltage relative to the earth/ground of this damaged phase becomes equal to zero, and voltages relative to the earth/ground of other two intact/uninjured/undamaged phases increase to the interphase voltage of installation (Fig. 5-2).

For example, during closing/shorting to the earth of phase C (Fig. 5-2a) a change in the voltage of phases relative to the earth/ground can be considered as the result of imposition on the voltages of phases $\dot{U}_A, \dot{U}_B$ and $\dot{U}_C$ the voltages of null sequence

$\dot U_{A0}$, $\dot U_{B0}$ and $\dot U_{C0}$, equal in magnitude and opposite on sign to the phase voltage of damaged phase $\dot U_C$. In this case the voltages of all phases relative to earth/ground $\dot U'_A$, $\dot U'_B$ and $\dot U'_C$ are determined by vector sum of the voltages of phases relative to the earth/ground in the normal mode of work $\dot U_A$, $\dot U_B$ and $\dot U_C$ and voltages of null sequence $\dot U_{A0}$, $\dot U_{B0}$ and $\dot U_{C0}$, namely:

$$\dot U'_A = \dot U_A + \dot U_{A0};\ \dot U'_B = \dot U_B + \dot U_{B0};$$

$$\dot U'_C = \dot U_C + \dot U_{C0} = 0.$$

From vector diagram in Fig. 5-2b it is evident that $U'_A = U'_B = \sqrt{3} U_A$. The angle between $\dot U'_A$ and $\dot U'_B$ composes 60°.

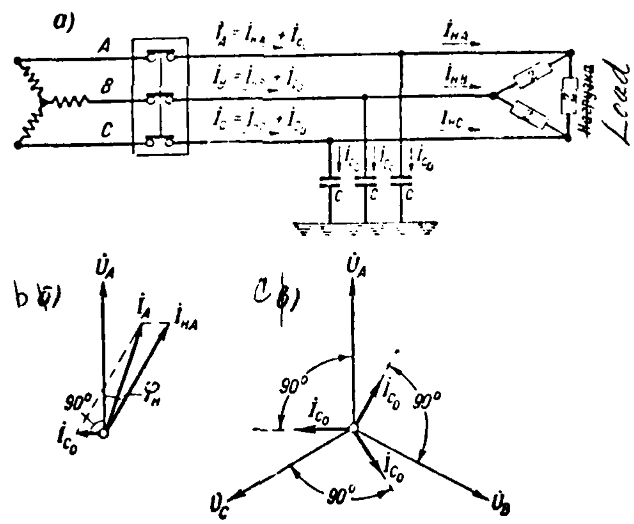
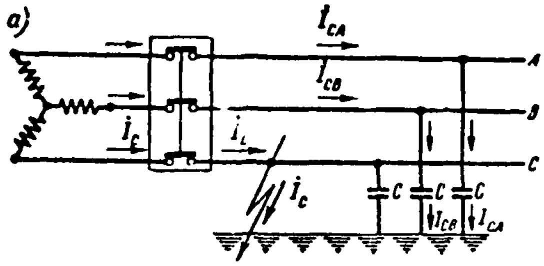


Fig 5.1

Fig. 5-1. Three-phase network with the ungrounded neutral. Normal mode of work.



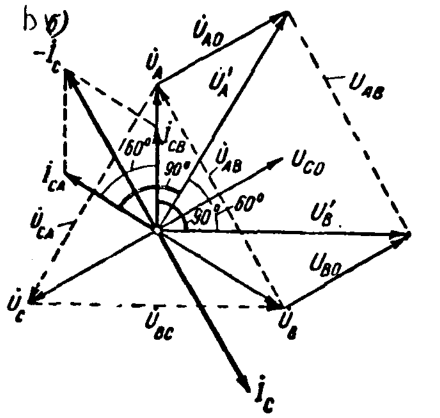


Fig. 5-2. Three-phase network with ungrounded neutral. Case of single-phase closing/shorting to the earth of phase C.

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Permittance currents in phases A and B also increase $\sqrt{3}$ times, since to the capacities/capacitances of these phases relative to the earth/ground (which remain constant/invariable) are applied no longer

phase, but interphase voltages. In symmetrical three-phase system $I_{CA}=\sqrt{3}I_{C_0}$ and $I_{CB}=\sqrt{3}I_{C_0}$. Permittance current to the earth of phase C, caused by its capacity/capacitance with respect to the earth/ground, is equal to zero, since the capacity/capacitance indicated proves to be shorted. Accepting, as usual, for positive direction of flow in all phases direction them from source into network, we can write:

$$I_C=-(I_{CA}+I_{CB}).$$

After applying on vector diagram in Fig. 5-2b vectors of currents I_{CA} and I_{CB} at right angles to the vectors of voltages $\dot{U}'_A$ and $\dot{U}'_B$, we can see that these currents are out of phase angle of 60°. We store/add up them and obtain current minus I_C, permittance current in phase C or, which is the same thing, the current in the place of closing/shorting to the earth I_C anticipates/leads $\dot{U}_C$ on 90°. From vector diagram it follows that $I_C=\sqrt{3}I_{CA}$, but that as $I_{CA}=\sqrt{3}I_{C_0}$, then

$$I_C=3I_{C_0}. \qquad (5\text{-}1)$$

Thus, the permittance current of single-phase closing/shorting to the earth is 3 times more than the normal permittance current of phase. Knowing the capacity/capacitance of phases with respect to C earth/ground in farads, we will obtain:

$$I_{C_0}=\frac{U_\Phi}{x_C},$$

on since

$$x_C = \frac{1}{\omega C},$$

that

$$I_C = 3U_\phi \omega C. \quad (5\text{-}2)$$

From this expression it is evident that the strength of current I_C depends on the line voltage, frequency and capacity/capacitance of phases relative to the earth/ground. The latter depends on the construction/design of network (cable or air) and its extent.

Current I_C can be approximately determined from the formulas:

for aerial networks

$$I_C = \frac{Ul}{350}; \quad (5\text{-}3)$$

for the cable systems

$$I_C = \frac{Ul}{10}. \quad (5\text{-}4)$$

where U - interphase voltage, kV; l - length of the electrically connected network of this voltage, km.

In the case of incomplete closing/shorting to the earth (through certain contact resistance) the voltage of the damaged phase relative to the earth/ground will be more than zero and less than the phase, but intact/uninjured/undamaged phases - more than phase, but less than the interphase. Less there will be the current of closing/shorting to the earth.

During single-phase closings/shortings to the earth in networks with the ungrounded neutrals interphase voltages remain constant/invariable in value and out of phase angle of 120°. Of this it is easy to be convinced from the examination of vector diagram in Fig. 5-2b:

$$\dot{U}'_{AB}=\dot{U}'_{A}-\dot{U}'_{B}=\dot{U}_{AB};$$
$$\dot{U}'_{BC}=\dot{U}'_{B}-\dot{U}'_{C}=\dot{U}'_{B}=\dot{U}_{BC};$$
$$\dot{U}'_{CA}=\dot{U}'_{C}-\dot{U}'_{A}=-\dot{U}'_{A}=\dot{U}_{CA}.$$

Therefore the feed of the electrical receivers, normally connected to interphase voltage, is not disrupted, and they continue to operate normally.

At the same time, taking into account increase indicated higher $\sqrt{3}$ times of the voltages of intact/uninjured/undamaged phases relative to the earth/ground, the phases of network with the ungrounded neutral must be isolated/insulated relative to the

earth/ground to interphase voltage.

Let us note that the prolonged work of the network in question with the grounded phase is not admitted, since in the case of damage to insulation relative to the earth/ground of any another phase unavoidably appears two-phase short circuiting through the earth/ground, which is accompanied by the course of large short-circuit current, capable of causing the considerable destruction of electrical equipment. Therefore in networks with the ungrounded neutrals compulsorily provide for the special signal or shielding (relay) devices/equipment, which notify personnel about the onset of single-phase closings/shortings to the earth or even the disconnecting the damaged part of installation.

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Is more dangerously single-phase closing/shorting to the earth through the electric arc, since the latter can damage electrical equipment and cause two- or three-phase short circuit (latter frequently is observed during single-phase closings/shortings to the earth of one of the veins/strands of triple-core cable). Is especially dangerous the onset of arc within machines and apparatuses during single-phase closings/shortings to the grounded housings.

Under specific conditions [5-1] in the place of closing/shorting to the earth can appear the so-called discontinuous arc, i.e., the arc which periodically goes out and lights up again. Since network is oscillatory circuit, then the discontinuous arc is accompanied by the origination of overvoltages of phases relative to the earth/ground whose value can reach $(2,5-3)\,U_{\Phi}$. These overvoltages are propagated to entire electrically connected network, as a result of which are possible the breakdowns of insulation and the formation/education of short circuits in the parts of the installation with the weakened insulation.

Is most probable the onset of the discontinuous arcs with the permittance current of closing/shorting to the earth of more than 5-10 A, the danger of arc overvoltages growing/rising with an increase in the line voltage. Are most dangerous arc overvoltages in networks by voltage 20-35 kV and above.

If installation is not equipped with relaying from single-phase closings/shortings to the earth, which disconnects the damaged section, then closing/shorting to the earth can be prolonged. In these cases the personnel must immediately to begin finding of the place of single-phase closing/shorting to the earth and to remove him within the shortest period. In the presence of stand-by circuit should be immediately transferred to it the feed of load, after

disconnecting faulted circuit. If there is no stand-by circuit, then the feed of the load is terminated on the period of clearing to circuit.

In the networks, which feed directly from the generators of power plants, the duration of work with closing/shorting of phase of of grounding must be not more than 2 h [3-2 and 5-2].

In electric systems by voltage 6-15 kV the overvoltages, caused by the discontinuous electric arc in the place of single-phase closing/shorting to the earth, for the insulation of electrical equipment are not dangerous. In spite of this, in these networks one ought not to allow/assume current I_C of more than 30 A, since with high currents I_C appears the danger of considerable damages in machines and apparatuses during internal single-phase closings/shortings to the grounded housings and grows/rises the transitional probability of single-phase closings/shortings to the earth in cables into interphase short circuits.

In contrast to this in electric systems by voltage 20 kV and above overvoltages, caused by the discontinuous arc in the place of single-phase closing/shorting to the earth, are dangerous for insulation the electrical equipment of the voltages indicated. Therefore in the networks of these voltages I_C must not exceed 10 A,

since with larger current in the place of closing/shorting to the earth, as a rule, appears the discontinuous electric arc.

Thus, with ungrounded neutrals can work networks 6-15 kV with $I_c \leq 30$ A and network 20-35 kV when $I_c \leq 10$ A [3-6]. Let us note that in the Soviet power systems of network 110 kV it is above with the ungrounded neutrals, as a rule, they do not work, that as with their considerable range current as with their considerable range current I_c in these networks virtually always exceeds 10 A.

With the ungrounded neutrals they work also of network by voltage of up to 1000V, besides four-wire networks by voltage 380/220 and 220/127/V, which work with tightly grounded neutrals (see §3-1).

5-2. Three-phase networks with the neutrals, grounded through the arc-arresting coils (compensated networks).

When in electric systems by voltage to 35 kV the inclusively permittance current of single-phase closing/shorting to the ground exceeds permissible value indicated above, then take measures for its decrease. Is reached this via the grounding of the neutrals of the network through the arc-arresting coils.

The arc-arresting coil consists of the steel core and the

winding, encased, filled with transformer oil. The effective resistance of coil is small, and inductive - great. The inductance of the arc-arresting coil regulate by change numbers of connected turns or air-gap clearance of core. In the normal mode of work the current through the coil does not flow/occur/last.

During full/total/complete closing/shorting to the earth of one phase the arc-arresting coil proves to be under phase voltage and through the place of closing/shorting to the earth flow/occur/last the currents: the permittance current of closing/shorting to the earth I_C and inductive current of coil I_L (Fig. 5-3a). Both inductive and permittance currents they differ in phase on 180°, then in the place of closing/shorting to the earth they compensate each other (Fig. 5-3b).

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If $I_L = I_C$, then through the place of closing/shorting to the earth of no current flow/occur/last there will be. Therefore of arc in the place of damage it does not appear and are removed the connected with it dangerous consequences.

In operation are conducted the start and the cutoff/disconnection of the individual lines of network; therefore

current I_C does not remain constant/invariable and virtually does not succeed in attaining, its full/total/complete compensation $(I_L \neq I_C)$. On the other hand, for the clear action of relaying, which reacts to single-phase closing/shorting to the earth, it is necessary that the uncompensated for current would not be the less specific value, with which the relay of protection operates/wears.

If the arc-arresting coil is inclined so that in normal mode with all killed lines of network occurs certain undercompensation of permittance current $I_{\text{неск}} = I_C - I_L$, then with the cutoff/disconnection of the part of the lines of network and decrease I_C current $I_{\text{неск}}$ can prove to be insufficient for acting relaying. During tuning of coil to overcompensation $(I_L > I_C)$ we will obtain that with decrease I_C current $I_{\text{перек}} = I_L - I_C$ increases. Therefore in practice they usually tune the arc-arresting coil with certain overcompensation of permittance current, but that so that the current in the place of shorting to the ground would be possibly less.

In networks with the neutrals, grounded through the arc-arresting coils, the same as in networks with the ungrounded neutrals, is allowed/assumed the temporary service with the locked to the earth phase until occurs the possibility to carry out the necessary switchings for the separation/department of the damaged section. The presence of the arc-arresting coils is especially

valuable during short-term closings/shortings to the earth, since in this case arc in the place of closing/shorting is extinguished and line is not disconnected.

In networks with the neutrals, grounded through the arc-arresting coils, that like in networks with the ungrounded neutrals, is allowed/assumed the temporary service with the locked to the earth phase until occurs the possibility to carry out the necessary switchings for the separation/department of the damaged section. The presence of the arc-arresting coils is especially valuable during short-term closings/shortings to the earth, since in this case arc in the place of shorting is extinguished and line is not disconnected.

In networks with the neutrals, grounded through the arc-arresting coils, during single-phase closings/shortings to the earth the voltages of two intact/uninjured/undamaged phases relative to the earth/ground increase $\sqrt{3}$ times, i.e., to interphase voltage; therefore the insulation of phases with respect to the earth/ground in such networks also must be carried out to interphase voltage as in networks with the ungrounded neutrals.

Networks with the ungrounded neutrals and with the neutrals, grounded through the arc-arresting coils, usually call networks with

the low currents of closing/shorting to the earth.

5-3. Three-phase networks with dully grounded neutrals.

The second method, which warns the onset of the discontinuous arcs and connected with them overvoltages during single-phase closings/shortings to the earth, is the dead ground of the neutrals of electrical network (Fig. 5-4). Actually/really, if in this network occurs closing/shorting to the earth of one phases, then the latter proves to be short-circuited through the earth/ground and the current of single-phase short circuit $I_K^{(1)}$ causes the action of relaying and the cutoff/disconnection of the switch of the damaged section of network.

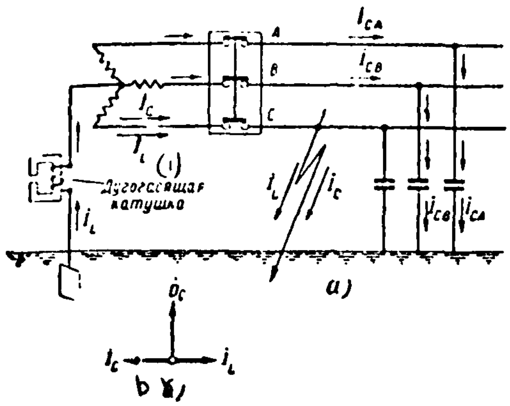

Fig. 5-3. Three-phase network with the neutral, grounded through the arc-arresting coil. Course of current during closing/shorting to the earth of phase C.

Key: (1). Arc-arresting coil.

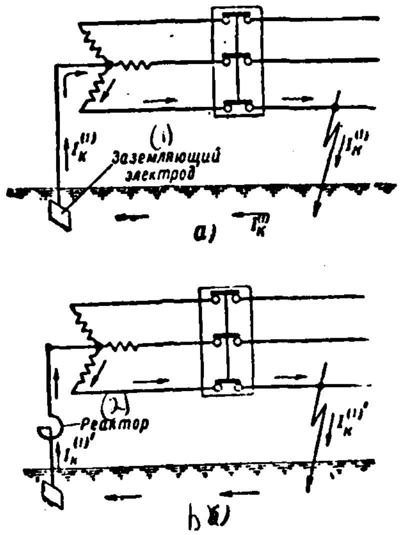

Fig. 5-4. Three-phase network with grounded neutral. a) network with dully grounded neutral; b) network with the neutral, grounded through the reactor.

Key: (1). Grounding electrode. (2). Reactor.

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A deficiency/lack in the networks with dully grounded neutrals is the significant magnitude of the current of single-phase short circuit. In networks with dully grounded neutrals of powerful/thick power systems for reduction in current of single-phase short circuit

ground the neutrals through reactors (Fig. 5-4b, $I_K^{(1)\prime} < I_K^{(1)}$) or are grounded the neutrals not of all transformers, but only part. By the installation of reactors and by the selection of a number of dully grounded neutrals it is possible to so decrease the current of single-phase short circuit, that it will not exceed the maximum possible current of three-phase short circuit in this installation.

The second deficiency/lack in the networks with the neutrals, grounded tightly or through reactors, is the cutoff/disconnection of damaged power transmission and, consequently, also break in the power supply of users during each single-phase closing/shorting to the earth. The practice of the operation of electrical devices shows that the large part of the single-phase closings/shortings to the earth in air electric systems by voltage above 1000V bears short-term character, since after the cutoff/disconnection of the damaged section insulation in the place of closing/shorting to the earth rapidly is restored, and the transmission line can be immediately connected into work. Therefore for the purpose increases in the reliability of power supply at present in networks with dully grounded neutrals use extensively the automatic reset (APV) of lines after their cutoff/disconnection during single-phase closings/shortings to the earth. For this it is included conversely. If closing/shorting to the earth was temporary/time, then line is included and the nourishment of users is restored. Otherwise the line

is disconnected for a second time. The reliability of the power supply of responsible users is provided also by the presence of stand-by electric power lines.

The advantage of networks with dully grounded neutrals is the fact that during single-phase closings/shortings to the earth the voltage of intact/uninjured/undamaged phases with respect to the earth/ground is not raised, as it takes place in networks with the neutrals, grounded through the arc-arresting coils. Therefore due to the facilitation of the insulation of phases with respect to the earth/ground significantly decrease the expenditures for the construction of such networks. Attained savings is greater, the higher the line voltage.

On the basis of the above in the USSR with dully grounded neutrals work the electric systems by voltage 110 kV and above. Such networks is conventionally designated as networks with the high currents of closing/shorting to the earth.

Chapter Six.

SHORT CIRCUITS IN ELECTRICAL SYSTEMS.

6-1. General information.

The large part of the emergencies in electrical systems is caused by short circuits. In many instances short circuits are accompanied by the damage electrical equipment and by the partial or full/total/complete disorder of the power supply of users.

The fundamental reason for short circuits is the insulation failure of the current-carrying parts of the electrical devices/equipment, which is possible as a result of the natural ageing (wear) of insulation, not in proper time revealed by preventive insulation tests, or its any damages in the process of the work of electrical equipment.

Mechanical damages to insulation occur, for example, with damage of power cables during the excavations of trenches, with the incidence/drop in the supports or the break of the wires of the air electric power lines, etc.

Damages to insulation are possible with overvoltages, if their value exceeds the testing voltage of the insulation of electrical equipment, for example, with the direct impacts of lightning into the wires of aerial lines or open distributors.

To short circuiting they can give the erroneous actions of operating personnel with the nonfulfillment by it of technical operation instructions, operating instructions and rules on safety engineering.

Short circuits are possible also as a result of the overlap of the bare current-carrying parts by the animals and birds.

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With the onset of short circuit general/common/total resistance of electrical system decreases, in consequence of which the currents in the branches of system considerably increase; simultaneously voltages in the individual parts of the system decrease. especially considerably decreases voltage near the place of short circuit.

The currents of emergency mode in the branches of system, and especially short-circuit current in the damaged element of system, can considerably exceed the currents of the loads of these branches.

In powerful/thick installations by voltage 6-20 kV the short-circuit currents reach enormous values - in several ten and even hundreds of thousands of amperes.

Considerable in value short-circuit currents can be dangerous for electrical equipment, since insufficiently durable in mechanical sense electrical equipment can be destroyed, and the large heating of current-carrying parts they can damage their insulation. For warning/prevention this electrical equipment of electrical devices/equipment must possess sufficient electrodynamic (mechanical) and thermal resistance, i.e., must maintain/withstand without the damages of the action of the greatest possible short-circuit currents.

The possibility of the disturbance/breakdown of the power supply of users during short circuits let us explain based on the example of the schematic of the simplest electric system, given in Fig. 6-1. Here diagram 1 shows the values of voltages on the busbars of station ($U_{\text{ст}}$), of distribution point RP ($U_{\text{РП}}$) and transformer substation TP ($U_{\text{ТП}}$) during the normal mode of work.

In the case of three-phase short circuit at point K-1 appears current of short, flowing along the generators of power plant and lines L-1 and L-2. In this case the voltage on busbars TP becomes

equal to zero, and voltages on busbars RP ($U'_{PП}$) and power plant (U'_{CT}) considerably are reduced (diagram 2). Is explained this by the fact that with the course of the short-circuit current which considerably which considerably more than the current of the normal mode of the elements/cells of network possesses large inductive component, in the first place, decreases emf of generators as a result of an increase in the back induction of the reaction of stator and, in the second place, increase the losses of voltage in all network elements of short circuit - generators and lines L-1 and L-2. Voltage at all points of power line will be lowered until is discontinued the course of short-circuit current, i.e., until is disconnected switch V-2 under the action of relaying of line.

Decrease in the voltage in power line deranges of electrical receivers. It is known that the torque of asynchronous electric motors is proportional to the square of conducted/supplied to them voltage ($M_{эд} \equiv U^2$), therefore even with comparatively small decrease in voltage $M_{эд}$ it can prove to be insufficient for rotating the mechanism (machine tool, etc.), and engine will stop.

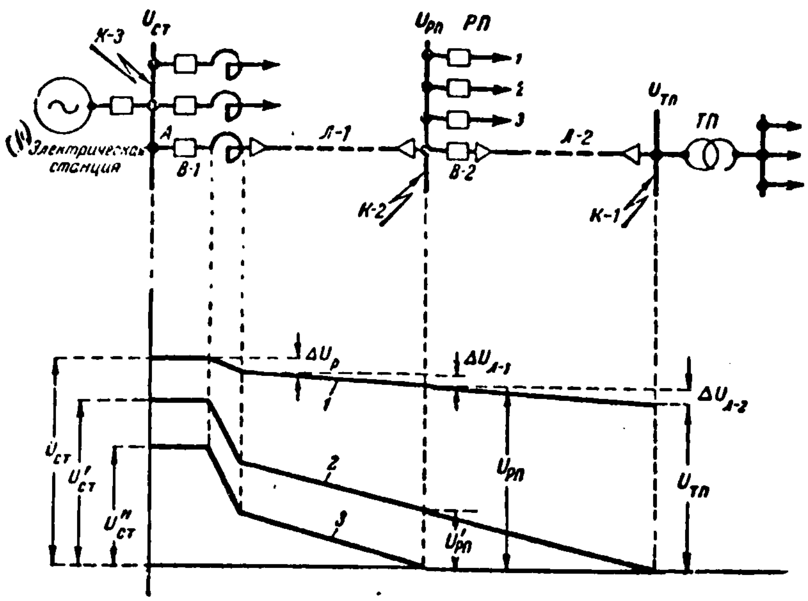

Fig. 6-1. Voltages in different points of network during normal mode and short circuits.

Key: (1). Electrical station.

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For example, if during short circuit at point K-1 voltage U'_{pn} proves to be small, then is possible the stop of the electric motors, which feed from other, sound lines RP (1, 2, 3).

If decrease in the voltage during short circuit is comparatively

small, then the electric motors, which feed from sound lines, continue to work, but with the rotational speed it is less than the normal. A decrease in the velocity of the rotation of those loaded electric motors leads to an increase in the current, consumed by them from network, which causes an even larger decrease in the conducted/supplied to them voltage, as a result of which the engines can stop.

In the case of prolonged short circuit the electric motors considerably overheat; the frequent overheatings of engines decrease the period of their service.

In certain productions large deceleration of the rotation of electric motors leads to the disorder of technological process, and sometimes also to the damage of production.

Thus, short circuit in network not only disrupts the power supply of the electrical receivers, connected after the place of the short circuit (in the examined case - receivers of TP), but it can cause the disturbance of the electrical receivers, connected to the intact/uninjured/undamaged sections of network.

In the case of short circuit at point K-2 the voltage on the busbars of station is reduced (diagram 3) still more than $(U''_{ст} < U'_{ст})$.

Switch V-1 disconnects line L-1, and the nourishment of all users RP ceases.

Thus, the nearer the short circuit to station, the the more number of users is disconnected. Furthermore, to larger degree is disrupted the work of the electrical receivers, which feed from the sound lines of station. Especially considerably is reduced voltage on the busbars of station in the absence of reactors on the waste/exiting lines.

The heaviest case of short circuit is short circuiting on the collecting mains of station (point K-3), when are disconnected the generators of station and ceases the feed of all its lines.

Short circuiting in the network of power system, which is accompanied by considerable decrease in the line voltage, can lead to the destabilization of the multiple operation of separate stations, their output from synchronism and cutoff/disconnection of the lines, which connect stations. As a result of this the system can be decomposed into the groups of the nonsynchronously working stations. This in turn, can lead to the overloading of some stations, which will require the cutoff/disconnection of the part of the users. The greater the decrease in the voltage during short circuits, the time of action of relaying and the time of action of the switch, which

disconnects the damaged section, the more probable the destabilization of the multiple operation of the stations of system.

For the purpose of the trouble-free operation of electrical installations it is necessary to in every possible way remove the reasons, capable of causing short circuits. For decreasing the consequences of short circuits should be applied high-speed relays and switches. It is also expedient to install on the station's generators automatic excitation regulators (see §22-5), which increase the generator excitation current during short circuitings, as a result of which the voltage in different parts of the network decreases less, and after cutoff of the short circuit, the voltage returns to normal more quickly.

In three-phase systems are possible three fundamental means of the short circuits: three-phase, two-phase and single-phase.

Three-phase short circuit (Fig. 6-2a) is symmetrical, that as with it is not disrupted the symmetry of currents and voltages (is assumed the equality of the resistors/resistances of three phases of short circuit). In contrast to normal mode the and phase and interphase voltages decrease, as this is shown on vector diagram of currents and voltages on Fig. 6-2b, in reference to the terminals/grippers of generator. The less the resistor/resistance of

network (r_c and x_c), the greater the short-circuit current and the less load voltage of generator. If contact resistance in the place of short circuit are equal to zero ("metallic" or "dead/blind" short circuit), then voltages in the place of short circuit are also equal to zero.

During three-phase short circuit the system remains balanced, since vector sums as currents, that and voltages in any place for short circuit remain equal to zero.

Angle of displacement φ_k between the current and the voltage during short circuit is determined by the relationship/ratio of the inductive and effective resistance of short circuit.

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At the relatively low value of the effective resistance of short circuit, which occurs with short circuits in installations by voltage above 1000V, angle φ_k lies/rests within limits of 90-30°, i.e., short-circuit current is either purely inductive or possessing considerable inductive component.

The two-phase (Fig. 6-2c) and single-phase (Fig. 6-2d) short circuits are asymmetric, since with them is disrupted the symmetry of

voltages and currents of three-phase system. Two-phase short circuit is at the same time balanced, since with it vector sums of voltages and currents remain equal to zero. In contrast to this single-phase short circuit is unbalanced, since with it short-circuit current flows/occurs/lasts only in one phase and vector sum of phase voltages no longer is equal to zero.

Vector diagrams of currents and voltages during asymmetric short circuits are examined into §6-12.

Three-phase and two-phase short circuits are possible in any three-phase networks, and the single-phase short short circuit - only in three-phase networks with dully grounded neutrals (see §5-3) and in four-wire networks by voltage 380/220 and 220/127V.

Currents, voltages, power and other values, which relate to different means of short circuit, designate by upper digital indices in the parenthesis: three-phase short circuiting - by index (3), two-phase - by index (2), single-phase - by index (1), as shown in diagrams and vector diagram in Fig. 6-2.

The computation of short-circuit currents is necessary for: 1) the selection of the electrical equipment: electrical apparatuses, busbars, insulators, power cables, etc.; 2) the selection of the

means of the limitation of short-circuit currents; 3) the design of relaying even 4) the analysis of emergencies in electrical systems.

For the solution the first two problems sufficiently knowing how to determine the short-circuit current, which flows into the place of damage, and in certain cases - also its distribution in the branches of system, which directly adjoin the place of damage. In this case in the majority of the cases completely sufficient is the approximate determination of the current of three-phase short circuit and less often than the current of the two-phase short circuit (see §6-12). During the design of relaying and the analysis of emergencies in electrical systems are required the determination of short-circuit currents in the various forms of short circuit, the determination of its distribution in the branches of system, during asymmetric short circuits the determination of currents in the damaged and intact/uninjured/undamaged phases, determination during the short circuits of voltages at different points of system.

Calculation of the mode/conditions of short circuit taking into account real characteristics and real mode of operation of all elements/cells of the power system, which unites frequently the large number of most varied power plants, is by very complicated and labor-consuming. At the same time for solving the majority of practical problems during design and operation of the electrical

devices turns out to be completely sufficient to have available approximate values of currents and voltages during short circuits.

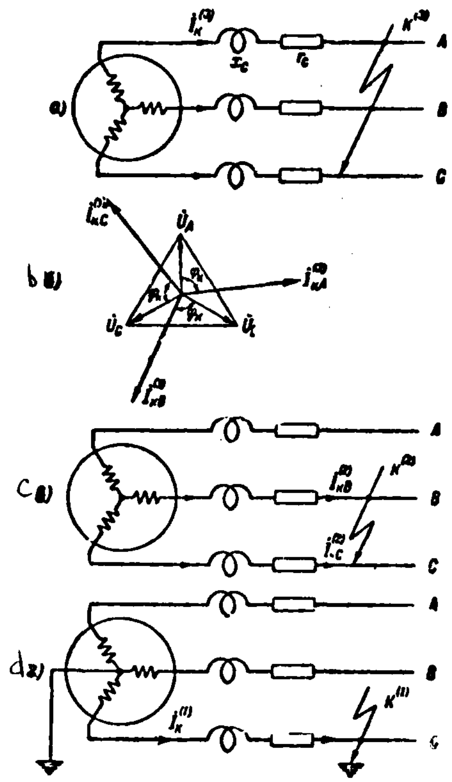

Fig. 6-2. Means of short circuits.

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Therefore during design and in operation as a rule, are utilized the approximation methods of the calculation of the mode/conditions of the short circuit, based on some conditional assumptions which substantially simplify and facilitate calculations and usually they

lead to the determination of the currents of short with exaggeration, i.e., with reserve (error in these, calculation methods it usually leaves order 10-15o/o).

Is presented below the conventional in Soviet practice approximation method of the calculation of currents and voltages during short circuits, in which are accepted the following fundamental assumptions:

1. They accept, that during entire process of the short circuit of emf of all generators the systems coincide in the phase (there are no oscillations of generators).

2. Is not considered saturation of magnetic system that it makes it possible to consider constants and not depending on current inductive resistors/resistances of all elements/cells of short-circuited circuit.

3. They disregard exciting currents of power transformers.

4. Is not considered capacity/capacitance of all elements/cells of short-circuited circuit, switching on air and cable lines (it is virtually necessary to consider capacity/capacitance only of very powerful/thick lines of large extent, for example lines by voltage

400-500 kV).

5. They consider that three-phase system is symmetrical.

Especially let us pause at the account of the effective resistance of network elements of short circuit. In installations by voltage above 1000V effective resistance of generators, power transformers and reactors are small in comparison with their inductive resistors/resistances and they little affect the value of short-circuit current. Therefore short-circuit current in these installations they usually calculate without taking into account the effective resistance of network elements of short circuit, taking into account only their inductive reactances. The effective resistance of air and cable lines is considered only with their large extent; in this case larger value has an account of the effective resistance of cable lines as a result of their relatively low inductive resistor/resistance. Usually the effective resistance of the circuit of short circuiting $(r_{рез})$ is expedient to consider only in such a case, when it is more than one third inductive reactance $(x_{рез})$ of the same circuit [6-1]:

$$r_{рез} > \frac{1}{3} x_{рез}. \qquad (6\text{-}1)$$

In installations by voltage of up to 1000V the effective resistance of network elements are relatively great; therefore the

currents of short after shorting in these installations should be calculated taking into account both the inductive and effective resistance of network elements of short circuit.

In the following below paragraphs of present chapter is examined the computation of currents with three-phase short circuiting. The computation of currents during asymmetric short circuits is examined in §6-12.

Briefly the order of the computation of currents during three-phase short circuits is reduced to the following. For the assigned in the electrical diagram place of short circuit connect the substitutions and by gradual conversion they lead it to one equivalent element/cell, which possesses certain resulting resistor/resistance $x_{рез}$ or $z_{рез}$, on the one hand of which it proves to be applied the resultant emf, and from other side is located the point of short circuit. Knowing resulting emf and resulting resistor/resistance, according to the law of ohm is determined the value of short-circuit current.

During the computation of short-circuit currents all entering the calculation values can be expressed in named units (kilo-volt-amperes, amperes, volts, ohms) or in relative units (fractions/portions or percentages of the basic quality accepted). In

Soviet designed and operating practice conventional is the second method of calculation, i.e., calculation in relative units. To the advantages of this method of calculation can be attributed the simpler structure of the majority of calculated expressions, the large clarity of the results of computation and possibility it is very rapid and it is simple to determine the order of computed magnitudes. Further on the course of the presentation of material will be shown other advantages of this method of calculation.

The major advantage of the method of calculation in named unity in connection with short-circuit study consists in the use of an Ohm's law in already familiar form.

Below material of present chapter is set forth in the following order. All processes and phenomena during short circuits are examined with the expression of values in named units (but resistors/resistances, and detail, in ohms), with exception of those cases when use of a system of relative unity gives the simpler or more demonstrative treatment of phenomena or processes.

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All fundamental calculated expressions are derived/concluded initially in the system of named unity, and only after this they are

led to the system of relative units, which facilitates the understanding of the physical essence of calculated expressions.

In examples the calculations are carried out predominantly in relative unity, although in some examples are given the versions of calculation and in named units.

6-2. System of relative units.

The computation of values in relative units, i.e., in fractions/portions or percentages of certain assigned, so-called basic quality widely was encountered already in all preceded disciplines: physics, theoretical electrical engineering, electric machines, etc.

As an example it is possible to indicate the determination in fractions/portions or percentages of the appropriate nominal values of loss or drop in the voltage, and also the power loss or energy in the elements/cells of electrical circuit. In relative unity accept to express the parameters of electrical machines and transformers, for example impedance voltage u_{κ}%. the slip, etc. The system of relative unity they widely use in many courses during the construction of standard characteristics and for other purposes.

Here we will examine the use of a system of relative unity in connection with the calculations of the mode/conditions of short circuits.

We will take any element/cell of three-phase electrical circuit with following rating factors $U_{ном}$ (kV), $I_{ном}$ (kA), $S_{ном}$ (MVA) and $x_{ном}$ (ohms) (we assume/set r=0), which are connected with the obvious conditions:

$$\left.\begin{aligned} S_{ном} &= \sqrt{3}\, U_{ном} I_{ном} \\ x_{ном} &= \frac{U_{ном}}{\sqrt{3}\, I_{ном}}. \end{aligned}\right\} \qquad (6\text{-}2)$$

Any other mode/conditions of the same network element is characterized by some values of voltage U, current I, power S=√3UI and resistor/resistance X=U/√3I, which can be expressed in the fractions/portions of the corresponding nominal sizes of this element:

$$\left.\begin{aligned} U_{*ном} &= \frac{U}{U_{ном}}; \quad I_{*ном} = \frac{I}{I_{ном}}; \\ S_{*ном} &= \frac{S}{S_{ном}}; \quad x_{*ном} = \frac{x}{x_{ном}}. \end{aligned}\right\} \qquad (6\text{-}3)$$

Obtained similarly values are the relative nominal values, which characterize network element under given conditions for its work (index asterisk * indicates that the value is expressed in relative units, and index $_{ном}$ - that it is referred to rating factors of this network element).

The clarity of the system of relative unity shows the following simple example. Let the generator with a nominal power of $S_{ном} = 37,5$ MVA with nominal by voltage $U_{ном} = 10,5$ kV work with load S=28.5 MVA with voltage U=10.2 kV. According to these data it is difficult to visualize the degree of utilization of a generator. However, resorting to the system of relative units, we obtain the following relative nominal values of load and voltage of the generator: $S_{*\,ном} = \frac{28,5}{37,5} = 0,76$ and $U_{*\,ном} = \frac{10,2}{10,5} = 0.97$, which already very clearly characterizes the mode/conditions of the work of generator.

The given above expression for relative nominal resistor/resistance $x_{*ном} = \frac{x}{x_{ном}}$ can be converted, after replacing $x_{ном}$ with its value from formula (6-2), then:

$$x_{*\,ном} = \frac{\sqrt{3}\, I_{ном} x}{U_{ном}}. \qquad (6\text{-}4)$$

Hence it follows that the relative nominal resistor/resistance is equal to a voltage drop in the resistor/resistance of this network element with the course through it of its rated current (with its nominal load), referred to its nominal voltage.

After replacing in formula (6-4) the rated current through nominal power, we will obtain:

$$x_{*\,ном} = \frac{S_{ном} x}{U^2_{ном}}. \quad (6\text{-}5)$$

Relative values of current, voltage and so forth can be calculated not only with respect to the nominal values of this network element, but also with respect to any other system of values, placed as the basis of calculation and being called base line system of values.

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Is obvious that into the base line system of values they must enter base line power $S_б$, base line voltage $U_б$ and base current $I_б$, connected with equation power of three-phase system $S_б = \sqrt{3} U_б I_б$. Therefore arbitrary to be assigned it is possible only by two basic qualities. Be assigned to usually more conveniently by base with a power of $S_б$ and voltage $U_б$ and by them to already determine the base line current:

$$I_б = \frac{S_б}{\sqrt{3} U_б}. \quad (6\text{-}6)$$

With known basic qualities $S_б, U_б$ and $I_б$ the relative base line values are determined from the following formulas, analogous formulas (6-3):

$$U_{*б} = \frac{U}{U_б};\ I_{*б} = \frac{I}{I_б};\ S_{*б} = \frac{S}{S_б}. \quad (6\text{-}7)$$

Relative base line resistor/resistance is determined from formulas, analogous to formulas (6-4) and (6-5):

$$x_{*6}=\frac{\sqrt{3}I_6x}{U_6} \qquad (6\text{-}8)$$

and

$$x_{*6}=\frac{S_6x}{U_6^2}. \qquad (6\text{-}9)$$

Thus, relative base line resistor/resistance is equal to the voltage drop in the resistor/resistance of this network element with the course through it of base line current, in reference to base line voltage.

Let us note that into formulas (6-4) and (6-8) to more conveniently substitute current in kiloamperes and kilovoltage, but into formulas (6-5) and (6-9) - kilovoltage, but power in megavolt-amperes.

From the same formulas it is possible to determine ohmage, knowing resistor/resistance in relative unity.

Analogously to formulas are determined r_* and r or z_* and z.

In general the system of basic qualities can be selected

arbitrarily; therefore one and the same physical quantity can have many relative base line values. The at the same time relative nominal value of the same value is unambiguous. Taking into account this, in catalogs and plant informational materials always are given only relative nominal values, i.e., determined at nominal power and with nominal voltage of machine or apparatus.

In certain cases relative values are expressed in percentages. It is obvious that Uo/o=U_*100; Io/o=I_*100; So/o=S_*100; xo/o=x_*100; ro/o=r_*100 and so forth.

Relative base line resistor/resistance can be determined by known relative nominal resistor/resistance (and vice versa), using the following formulas, obtained from formulas (6-4) and (6-8):

$$x_{*б}=x_{*\,ном}\frac{I_б}{I_{ном}}\frac{U_{ном}}{U_б} \qquad (6\text{-}10)$$

or from formula (6-5) and (6-9):

$$x_{*б}=x_{*\,ном}\frac{S_б}{S_{ном}}\frac{U^2_{ном}}{U^2_б}. \qquad (6\text{-}11)$$

In conclusion let us point out that with the use of the system of relative values should be considered the numerical equality of the relative values of interphase and phase voltages, which is evident from the following: $U_{*\,межд}=\frac{U}{U_б}=\frac{U_ф}{U_{ф.б}}=U_{*ф}$. Therefore in the system of relative unity Ohm's law takes the form (index b is omitted)

$I_* = \frac{U_*}{x_*}$, and the formula of three-phase power takes the form $S_* = I_* U_*$. In this case, obviously, all entering the calculation values must be determined under identical conditions - nominal or base line.

6-3. Network of installation.

Short-circuit currents calculate, using the simplified unilinear diagram of installation (Fig. 6-3), which is called of calculation. In this diagram indicate all elements/cells of installation and their rating factors, which must be taken into consideration during the computation of short-circuit current. In installations by voltage above 1000V are considered the resistors/resistances of alternators, compensators, electric motors, power transformers, reactors, air and cable lines.

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The resistors/resistances of the busbars of distributors, coupling cables of comparatively small length and electrical apparatuses (switches, current transformers, etc.) do not consider in view of their small value.

In installations by voltage of up to 1000V to the value of short-circuit currents significantly affect not only the

resistors/resistances of the fundamental elements/cells of the short-circuited circuit, but also of such elements/cells as cables and busbars by length on the order of 10-15 m and more, the primary windings of current transformers (multiturn), coils of the maximum current of automata, contacts of knife switches and automata, etc. In this case it is possible not to consider those network elements whose total effect on the value impedance of circuit does not exceed 10o/o [3-6].

Instructions about the account of the effective resistance of the elements/cells of the short-circuited circuit were given in §6-1.

For the selection of electrical equipment must be determined the greatest possible values of short-circuit currents in this installation. But at the same time must not be introduced any aggravating conditions, which do not correspond to standard conditions of operating the electrical device. Therefore during the composition of network one should proceed from the provided for this installation normal conditions of the connection of the feeding aggregates/units and circuits.

In the presence of aggregates/units or circuits which on conditions of normal operation it cannot be connected in parallel (for example, the step-down transformers, air or cable lines, etc.),

they compose network on the basis of their separate work. Separate work they accept also when the parallel connection of aggregates/units or circuits is allowed/assumed only briefly temporarily during operational switchings, for example the start of stand-by transformer with the subsequent cutoff/disconnection of worker or the preliminary start of stand-by line with the subsequent cutoff/disconnection of worker (manual or automatic). at the same time, if in the conditions of increasing the reliability of the feed of users or increase in the efficiency/cost-effectiveness of the operation of substation stand-by transformer can be long connected to multiple operation with working transformers, then this mode/conditions should be accepted during the composition of network of substation.

If the collecting mains of installation are reacted, then one should proceed from the normal mode of the work of installation with the connected reactors between the sections of collecting mains.

During the peak load of system in work can be located all generators or all power plants of power system, which can be necessary both of the considerations for providing the most economical mode/conditions of the work of system as a whole and for providing the accident-free supply of users in the case of any emergency cutoffs/disconnections in system. Therefore during the

computation of short-circuit currents for a selection electrical equipment assume the simultaneous multiple operation of all generators of the power system both workers and stand-by ones [3-6].

The synchronous condensers and synchronous electric motors with short circuiting behave just as the generators: they generate current into the place of short circuit. Therefore during the composition of network should be switched on in it also the synchronous condensers and synchronous electric motors, examining them during the calculation of short-circuit currents kA generators. At the same time one should bear in mind that the small synchronous electric motors (in total power less than 1000 kVA) and especially considerably distant from the place of short circuit greatly little affect the value of short-circuit current and therefore they can be disregarded.

On the effect of asynchronous electric motors on short-circuit current it is stated below into §6-11.

During the computation of currents of short circuiting they conditionally consider that all synchronous machines to short circuit worked with full/total/complete nominal load with nominal factor of power and nominal load voltage.

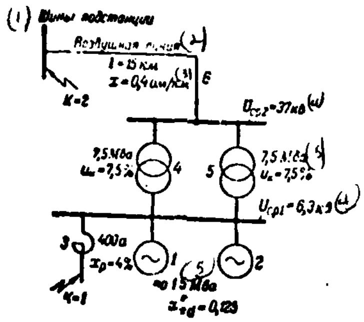

Fig. 6-3. Unilinear network of installation.

Key: (1). Busbars of substation. (2). Aerial line. (3). Ω/km. (4). kV. (5). MVA.

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Furthermore, they accept, what all synchronous machines are equipped with the automatic field regulators or with other devices/equipment, which increase their excitation with a decrease in the voltage as a result of short circuit (over-excitation, compounding - see §22-5).

Network should be also composed taking into account the predicted to the next 10 years development both this installation and that power system in which it works.

During the design of relaying the currents of short circuiting can be determined, also, under other conditions for the work of installation and system as a whole, which finds the appropriate reflection in comprised network. For example, can prove to be necessary the determination of short-circuit current with an incomplete number of working generators.

In general on network there can be several electrical steps/stages of different voltages, connected with transformers (on Fig. 6-3 two steps/stages of the voltage: 6.3 and 37 kV). For the purpose simplifications in the calculations (see §6-4) for each electrical step/stage instead of of it actually/really the voltage accept medium nominal voltage U_{cp} according to the following scale: 525; 420; 230; 162; 115; 37; 18; 15.75; 13.8; 10.5; 6.3; 3.15; 0.525; 0.4 and 0.23 kV.

On the collecting mains of network must be shown these medium nominal voltages.

For the explanation of medium nominal voltage let us turn to the diagram in Fig. 6-4, on which is shown raising transformer T, which feeds electric power line L. The great voltage U_1 in the beginning of line will be with the idling of transformer, and small voltage at the end of line U_2 - with its work with full load. Then for the

step/stage of the voltage of line L the mean nominal voltage $U_{cp}=\frac{U_1+U_2}{2}$. For example in networks 110 kV U_1=121 kV, U_2=110 kV, $U_{cp}=\frac{121+110}{2}\approx 115$ kV.

After accepting for each electrical step/stage medium nominal voltage, they consider that the nominal voltages of all elements/cells, connected at this step/stage, are equal to its medium nominal voltage. However, the miscalculation of short-circuit currents is obtained insignificant.

On network of the installation (see Fig. 6-3) indicate nominal power (kVA or MVA) and relative nominal resistors/resistances of the elements/cells which must be taken into consideration during the computation of short-circuit currents. For reactors indicate their rated currents, for air and cable lines - length and inductive ohmage to kilometer, but if they intend to consider effective resistance, then section and material of wires or strand of cable.

Are given below the exemplary/approximate values of the resistors/resistances of elements/cells, considered during the computation of short-circuit currents.

Synchronous machines. In the set-forth below the practical method of calculation of the currents of three-phase short circuit,

the synchronous machines are considered by their inductive reactance for an initial moment of short circuit, by so-called ultratransitory resistor/resistance along the longitudinal axis of poles x_d'' . [6-2].

The relative nominal values of ultratransitory resistors/resistances x_{*d}'' for different types of synchronous machines comprise:

(1) турбогенераторов двухполюсных	0,09—0,20
(2) гидрогенераторов без успокоительных обмоток	0,3—0,38
(3) гидрогенераторов с успокоительными обмотками	0,14—0,30
(4) синхронных компенсаторов	0,15—0,20
(5) мощных синхронных электродвигателей	0,18—0,38

Key: (1). the turbogenerators of two-pole ones. (2). hydraulic generators without damper windings. (3). hydraulic generators with damping windings. (4). synchronous condensers. (5). powerful/thick synchronous electric motors.

More precise values x_{*d}'' are given in catalogs and plant materials (see in appendix table P-1, P-2, P-3).

Power transformers and autotransformers. Double wound transformers. For each transformer there is known its impedance voltage u_k%, the numerical equal to a voltage drop in transformer with its nominal load, expressed in percentages of its nominal voltage.

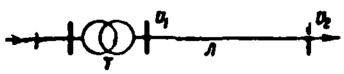

Fig. 6-4. Diagram to the explanation of the medium nominal voltage of electrical step/stage.

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Therefore, on the basis of data in §6-2 determinations of relative nominal resistor/resistance, it follows that $u_к\% = z_т\%$.

The effective resistance of high-voltages transformer is small; therefore for them, as a rule, accept $x_{*т} = \frac{u_к\%}{100}$.

During the computation of short-circuit currents in installations to 1000V they consider as that active, and inductive reactances of transformers.

The effective resistance of such transformers easily is determined, if are known the losses of short circuit $P_к$ of transformer, i.e., power loss in the windings of transformer with its nominal load:

$$P_{\kappa} = 3I^2_{\text{т.ном}} r_{\text{т}},$$

whence

$$r_{\text{т}} = \frac{P_{\kappa}}{3I^2_{\text{т.ном}}}. \qquad (6\text{-}12)$$

Since $z_{*\text{т}} = \frac{u_{\kappa}\%}{100}$, then, being guided by formula (6-5), it is possible to determine impedance of transformer in the ohms:

$$z_{\text{т}} = \frac{u_{\kappa}\% U^2_{\text{т.ном}}}{100 S_{\text{т.ном}}}.$$

Then inductive reactance of the transformer

$$x_{\text{т}} = \sqrt{z_{\text{т}}^2 - r_{\text{т}}^2}, \qquad (6\text{-}13)$$

where $r_{\text{т}}$ and $z_{\text{т}}$ must be related to one voltage.

The same resistors/resistances of transformer can be determined in relative unity. Being guided by formula (6-5), we determine the relative effective resistance of the transformer:

$$r_{*\text{т}} = \frac{S_{\text{т.ном}} r_{\text{т}}}{U^2_{\text{т.ном}}}.$$

After substituting into latter/last expression value $r_{\text{т}}$ according to formula (6-12), we will obtain:

$$r_{*\text{т}} = \frac{P_{\kappa}}{S_{\text{т.ном}}}. \qquad (6\text{-}12,a)$$

Relative inductive reactance of transformer, assuming/setting $z_{*\text{т}} = \frac{u_{\kappa}\%}{100}$,

$$x_{*т} = \sqrt{z_{*т}^2 - r_{*т}^2} = \sqrt{\left(\frac{u_к\%}{100}\right)^2 - \left(\frac{P_к}{S_{т.ном}}\right)^2}. \quad (6\text{-}13,a)$$

Value $u_к\%$ they take according to GOST 401-41 or catalogs upon power transformers (table P-4). For double wound transformers $u_к\% = 5{,}5 - 14\%$.

Triple-wound transformers (Fig. 6-5a) and autotransformers (Fig. 6-5b) are characterized by values $u_к\%$ for each pair of the windings: $u_{кВ-С}\%$; $u_{кВ-Н}\%$ and $u_{кС-Н}\%$, led to the nominal power of transformer or autotransformer (nominal power of the latter is equal to its transfer power - see chapter 23). The replacement scheme of three-winding transformer or autotransformer is given in Fig. 6-5c. Inductive reactances of the rays/beams of the equivalent star of replacement scheme can be determined from the formulas:

$$\left.\begin{aligned} x_{*В} &= 0{,}5\,(u_{*кВ-С} + u_{*кВ-Н} - u_{*кС-Н}); \\ x_{*С} &= 0{,}5\,(u_{*кВ-С} + u_{*кС-Н} - u_{*кВ-Н}); \\ x_{*Н} &= 0{,}5\,(u_{*кВ-Н} + u_{*кС-Н} - u_{*кВ-С}). \end{aligned}\right\} \quad (6\text{-}14)$$

Reactors. Inductive reactance of reactor determine by calculation, on the basis of need the limitations of the current of short circuiting to the specific value (see Chapter 8). On stations and substations most frequently are applied the reactors with resistor/resistance $x_р$ from 3 to 10o/o (see table P-7).

Air and cable lines. Reactance to the phase of lines can be accepted on the basis of the following average/mean values:

(1) для воздушных линий 6—220 *кв* (на одну цепь)	0,4	(2) *ом/км*
(3) для воздушных линий напряжением до 1 000 *в*	0,3	»
(4) для трехжильных кабелей 35 *кв*	0,12	»
» » » 3—10 *кв* (5)	0,07—0,08	»
» » » (6) до 1 *кв* (5)	0,06—0,07	»

Key: (1). for aerial lines 6-220 kV (to one circuit). (2). Ω/km. (3). for aerial lines by voltage of up to 1000V. (4). for triple-cores cable 35 kV. (5). kV. (6). to.

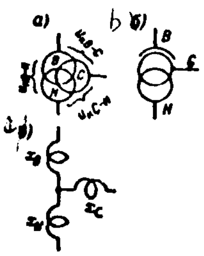

Fig. 6-5. Triple-wound power transformer (a), triple-wound autotransformer (b) and replacement scheme of their (c).

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The effective resistance of wires and cables is taken by reference tables or they determine from the generally known formula:

$$r=\frac{l}{\gamma s}. \qquad (6\text{-}15)$$

where r - active resistance of line, ohm;

l - length of line, m;

γ - specific conductivity (for copper γ=53; for aluminum γ=32), m/ohm•mm²;

s - section of wires, mm².

Busbars. Inductive reactance of rectangular busbars during the location of phases in one plane with distance of a between the axes of the phases (see Fig. 10-3), as it is usually accept in installations by voltage to 1000 V, it is possible to determine from the following approximation formula:

$$x = 0,145 \lg \frac{4a_{cp}}{h} \text{ [мОм/м]}. \quad (6\text{-}16)$$

Key: (1). mΩ/m.

where $a_{cp} = \sqrt[3]{a_{12}a_{13}a_{23}}$ - geometric mean distance between centers of phases, mm; with the location of phases in one plane and equal distance between them $a_{cp} = 1,26a$; h - height of rectangular busbar, mm.

The effective resistance of busbars is determined from formula (6-15).

Apparatuses. Active and inductive reactances of apparatuses, considered during the determination of short-circuit currents in installations by voltage to 1000 V, accept according to plant data (to catalogs) or results of measurements.

6-4. Determination of the resulting resistor/resistance of short circuit.

Replacement scheme. On network of setting up plan the calculation points of short circuit. If short-circuit current determine for testing electrical equipment to stability with short circuit, then calculation points must be outlined then so that over selected electrical equipment would flow/occur/last the greatest

possible short-circuit current during the assigned mode/conditions of the work of the setting up (for greater detail, see Chapter 21). Then for the selected point of short circuit connect the substitutions of the setting up, in which all network elements show connected electrically (magnetizing currents of transformers they disregard). Each network element in replacement scheme they designate by the fraction: in numerator is set itself the reference number of element/cell, and in denominator - values of the inductive and effective resistance (if the second they do not disregard).

In the form of an example Fig. 6-6 gives two replacement schemes, comprised for points K-1 and K-2 of network in Fig. 6-3 (values of resistors/resistances are determined below in example of 6-1).

Since the magnetizing currents of power transformers during the computation of short-circuit currents do not consider, then into replacement scheme double wound transformer should be introduced one resistor/resistance, equal to the sum of resistors/resistances of both its windings.

During the composition of replacement scheme it is necessary to indicate in it only those resistors/resistances over which flows/occurs/lasts the designed short-circuit current. So, into

replacement scheme for point K-1 are introduced inductive reactances of generators and reactor, but inductive reactances of transformers and of aerial line are not introduced, since during short circuit at point K-1 that of the short circuit through them does not flow/occur/last (station works isolated/insulated, without connection/communication with system). On the contrary, into replacement scheme for point K-2 are introduced the resistors/resistances of transformers and line, but the resistor/resistance of reactor is not introduced.

Total or as it accept to call, the resulting resistor/resistance of short circuit can be determined in named or relative unity.

The determination of resulting ohmage. If network has several magnetoconnected circuits (several network elements at the different electrical steps/stages, connected with transformers - a diagram in Fig. 6-7), then the resistors/resistances of all network elements must be given to one and the same base line voltage (to voltage one and the same electrical step/stage).

During the determination of short-circuit current, which flows into the place of short circuit, it is more convenient for base line voltage to accept the medium nominal voltage of that step/stage on which assumed short circuit.

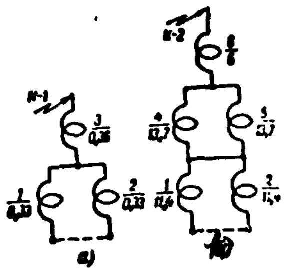

Fig. 6-6. Replacement schemes for the points of the short circuit K-1 (diagram a) and K-2 (diagram b) network in Fig. 6-3.

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Bringing the resistor/resistance, expressed in ohms, to the selected base line voltage is produced according to the formula:

$$\overset{*}{x} = x(k_1 k_2 k_3 \ldots k_n)^2, \qquad (6\text{-}17)$$

where $k_1, k_2, k_3 \ldots k_n$ - transformation ratios of the transformers through which resistance x is connected with the step/stage of the base line voltage; transformation ratios are determined in direction from the selected base line step/stage to that step/stage, at which is connected the element/cell whose resistor/resistance they lead to base line voltage.

In accordance with indications §6-3 for each step/stage they accept medium nominal voltage; therefore also transformation ratios

it is necessary to define as the relation of the medium nominal voltages of steps/stages.

For example, for the diagram in Fig. 6-7, on which are shown the medium nominal voltages of steps/stages and resistor/resistance of network elements, in reference to the appropriate medium voltages (x_1 - to U_1; x_2 and x_3 - to U_2; x_4 and x_5 - to U_3 and x_6 - to U_4), the resistors/resistances, led to base line voltage $U_6 = U_4$ will be:

for a generator G

$$\dot{x}_1 = x_1 \left(\frac{U_4}{U_3} \cdot \frac{U_3}{U_2} \cdot \frac{U_2}{U_1}\right)^2 = x_1 \left(\frac{U_4}{U_1}\right)^2 = x_1 \frac{U_6^2}{U_1^2};$$

for transformer T-1

$$\dot{x}_2 = x_2 \left(\frac{U_4}{U_3} \cdot \frac{U_3}{U_2}\right)^2 = x_2 \left(\frac{U_4}{U_2}\right)^2 = x_2 \frac{U_6^2}{U_2^2};$$

for line L-1

$$\dot{x}_3 = x_3 \left(\frac{U_4}{U_3} \cdot \frac{U_3}{U_2}\right)^2 = x_3 \frac{U_6^2}{U_2^2}$$

and so forth.

Thus, because of the fact that for each step/stage accept the medium nominal voltage, the intermediate coefficients of transformation are reduced and the translation of resistors/resistances can be conducted directly on base line voltage

according to the formula:

$$x_{U_б}=x_{U_{cp}}\frac{U_б^2}{U_{cp}^2}, \quad (6\text{-}18)$$

where $x_{U_б}$ - inductive ohmage to the phase of this element/cell, led to base line voltage $U_б$ accepted (sign of bringing ° it is omitted);

$x_{U_{cp}}$ - inductive ohmage to the phase of this element/cell with medium nominal voltage U_{cp} of that step/stage, on which is connected this element/cell.

Analogously lead to $U_б$ active and impedances.

Scale U_{cp} was given to §6-3.

After indicating in the diagram of the substitution of the resistor/resistance of all elements/cells in ohms, led to base line voltage, via known from theoretical electrical engineering rules convert diagram, giving it to to ever simpler form, and determine resulting resistor/resistance $x_{рез}$ or $z_{рез}$ circuits to the point of the short circuit (see below examples of calculation).

The determination of the resulting resistor/resistance in relative unity is possible only in such a case, when the relative

resistors/resistances of all network elements are calculated under one and the same base line conditions. For example, if in circuit are two elements/cells with rating factors S_1, I_1, U_1, x_{*1} and S_2, I_2, U_2, x_{*2}, then it is simple to accumulate values x_{*1} and x_{*2} is cannot, since they are determined in different rating factors. But if the relative resistors/resistances of these elements/cells are determined with the same power (current) and are related to one and the same voltage, i.e., we calculate under identical base line conditions, then the resulting resistor/resistance can be determined by the usual conversions of replacement scheme.

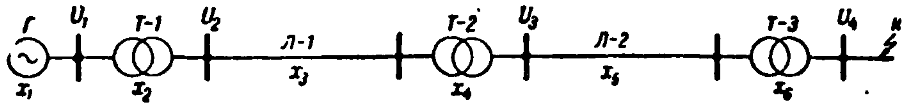

Fig. 6-7. Schematic of network/grid with several steps/stages of transformation.

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For bringing the resistors/resistances to the base line conditions accepted it is possible to use formulas (6-10) and (6-11), brought out into §6-2. According to the condition, accepted in §6-3, the nominal voltages of all network elements of short circuit equate with the medium nominal voltages of the corresponding steps/stages; therefore formula (6-11) in connection with generators and transformers takes the form:

$$x_{*б} = x_{*ном} \frac{S_б}{S_{ном}}, \qquad (6\text{-}19)$$

and formula (6-10) reactors in connection with takes the form:

$$x_{*р.б} = x_{*р.ном} \frac{I_б}{I_{р.ном}}. \qquad (6\text{-}20)$$

With the use of latter/last formula it is necessary to keep in mind that $I_б$ must be determined with the medium voltage of that electrical step/stage, on which is established/installed the reactor.

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ELECTRICAL EQUIPMENT OF ELECTRICAL STATIONS AND SUBSTATIONS,(U)

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Here it should be noted that when reactor is utilized in the setting up of smaller voltage, for example during the use of a reactor by a voltage 10 kV in setting up by a voltage 6 kV, it is necessary to consider a difference in the nominal voltage of reactor from the medium voltage of the step/stage where it is established/installed, and to determine its relative base resistor/resistance by formula (6-10).

For the air and cable lines, and also other elements/cells whose resistor/resistance is known in ohms, bringing to base line conditions is performed as follows. According to formula (6-5) resistor/resistance in relative unity (assuming/setting $U_{ном}=U_{cp}$) $x_{*ном}=\frac{S_{ном}x}{U_{cp}^2}$. Bringing to base line power according to formula (6-19) gives:

$$x_{*б}=\frac{S_б x}{U_{cp}^2}, \qquad (6\text{-}21)$$

where U_{cp} - medium nominal voltage of that electrical step/stage in circuit of which is connected this resistor/resistance.

Let us recall again that into formula (6-21) $S_б$ one should substitute in megavolt-amperes, and U_{cp} - in kilovolts.

According to analogous formulas they lead to base line conditions active and impedances.

Having shown in the diagram of substitution all led to base line conditions relative resistors/resistances, by the gradual conversion of diagram determine the resulting resistor/resistance of short circuit in relative unity $x_{*рез}$ (or $z_{*рез}$).

Of that presented earlier and formulas (6-8) and (6-9) it follows:

$$x_{*рез}=\frac{\sqrt{3}\,I_б x_{рез}}{U_б}=\frac{S_б x_{рез}}{U_б^2}. \qquad (6\text{-}22)$$

If after $U_б$ accept $U_{ср}$ the step/stage of short circuit $x_{рез}$ is referred to this voltage, then by $x_{*рез}$ should be understood a voltage drop in the total resistance of short circuit when the load of all elements/cells of this circuit is equal to base line power $S_б$, accepted referred to the accepted as base line medium voltage of the step/stage of short circuit.

Thus, $x_{*рез}$ is the conditional calculated value, which depends on base line conditions $(x_{*рез}\equiv S_б)$. accepted. Since $S_б$ can be selected arbitrarily, then for this point of short circuit $x_{*рез}$ can have different values less or large unity.

Value $S_б$ accepted must be conveniently for the computations; in many instances is convenient to take as $S_б$ the equal to 100 or 1000 MVA.

In the practice of calculations is used extensively also the so-called calculated resistor/resistance of short circuit $x_{*расч}$, under which is understood the total resistance of circuit, which consists of relative inductive reactance for initial the moment/torque of short circuit x''_{*d} of generators and external resisting from generators to the point of short circuit, referred to the total power of generators $S_{номΣ}$, from which is calculated the short-circuit current.

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From the aforesaid it follows:

$$x_{*расч} = x_{*рез} \frac{S_{номΣ}}{S_б}, \qquad (6\text{-}23)$$

where $x_{*расч}$ - calculated inductive reactance of short circuit, in reference to the total power of generators $S_{номΣ}$;

$x_{*рез}$ - resulting inductive reactance of short circuit, in reference to arbitrarily selected base line power $S_б$.

Let us note that $x_{*расч}$ unambiguously characterizes the electrical distance of the point of short circuit from electric power sources.

Everything said in ratio $x_{*рез}$ and $x_{*расч}$ to equal degree is related also to impedance of short circuit $z_{*рез}$ and $z_{*расч}$.

Example of 6-1. To determine resulting ohmage and relative unity to points K-1 and K-2 of network in Fig. 6-3, on which are shown all necessary calculations of value. Effective resistance not to consider. Nominal voltages of all elements/cells of network to consider equal to the medium nominal voltages of the corresponding steps/stages.

Calculation in ohms. Replacement schemes are given in Fig. 6-6.

We determine resulting resisting of circuit to point K-1. Base line voltage $U_б = U_{cp1} = 6{,}3$ kV.

Resisting of generators with voltage 6.3 kV we determine, utilizing formula (6-5):

$$x_1 = x_2 = \frac{x_{*\,ном} U^2_{ном}}{S_{ном}} = \frac{0{,}125 \cdot 6{,}3^2}{15} = 0{,}33 \text{ ом}^{(1)}.$$

Key: ohm.

resisting of reactor, being guided by formula (6-4):

$$x_3 = \frac{x_{*\,\text{ном}} U_{\text{ном}}}{\sqrt{3}\, I_{\text{ном}}} = \frac{4 \cdot 6{,}3}{100\sqrt{3} \cdot 0{,}4} \approx 0{,}36 \ \overset{(1)}{\text{ом.}}$$

Key: (1). ohm.

Having connected the neutral of the windings of generators as the points of midpotential, we obtain the simplest diagram, which consists of two parallel ones and one series resistance (see the diagram in Fig. 6-6a), from which we find:

$$x_{\text{рез}\,K\text{-}1} = \frac{x_1 x_2}{x_1 + x_2} + x_3 =$$
$$= \frac{0{,}33}{2} + 0{,}36 \approx 0{,}53 \ \overset{(1)}{\text{ом.}}$$

Key: (1). ohm.

We determine resulting resisting of circuit to point K-2. Base line voltage $U_б = U_{\text{ср}\,2} = 37$ kV.

Resisting of generators we lead to base line voltage, utilizing formula (6-18):

$$x_1 = x_2 = x_{U_{\text{ср}}} \frac{U_б^2}{U_{\text{ср}}^2} = 0{,}33 \frac{37^2}{6{,}3^2} = 11{,}4 \ \overset{(1)}{\text{ом.}}$$

Key: (1). ohm.

Resisting of transformers with base line voltage we determine,

utilizing formula (6-5):

$$x_4 = x_5 = \frac{u_к\% U^2_{ном}}{100 S_{ном}} = \frac{7,5 \cdot 37^2}{100 \cdot 7,5} = 13,7 \overset{(1)}{ом.}$$

Key: (1). ohm.

Inductive reactance of line with voltage 37 kV

$$x_6 = 0,4l = 0,4 \cdot 15 = 6 \overset{(1)}{ом.}$$

Key: (1). ohm.

From replacement scheme in Fig. 6-6b we find:

$$x_{рез\ K\text{-}2} = \frac{x_1 x_2}{x_1 + x_2} + \frac{x_4 x_5}{x_4 + x_5} + x_6 = \frac{11,4}{2} + \frac{13,7}{2} + 6 \approx 18,6 \overset{(1)}{ом.}$$

Key: (1). ohm.

Per unit calculation. Replacement schemes are given in Fig. 6-8.

We determine resulting resisting of circuit to point K-1.

We accept $S_б = 100$ MVA and we lead to it all resisting.

Relative base line resisting of generators according to formula (6-19):

$$x_1 = x_2 = x_{*\,\text{ном}} \frac{S_б}{S_{\text{ном}}} = \\ = 0,125 \frac{100}{15} = 0,83.$$

For determining relative base line resisting of reactor from formula (6-20) we determine the base line current

$$I_б = \frac{S_б}{\sqrt{3}U_б} = \frac{100}{\sqrt{3 \cdot 6,3}} \approx 9,2 \overset{(1)}{\text{ка}},$$

Key: (1). kA.

then

$$x_3 = x_{*\,\text{р.б}} = x_{*\,\text{р.ном}} \frac{I_б}{I_{\text{р.ном}}} = \frac{4}{100} \cdot \frac{9,2}{0,4} \approx 0,92.$$

Converting diagram in Fig. 6-8a, we obtain:

$$x_{*\text{рез}K\text{-}1} = \frac{x_1}{2} + x_3 = \frac{0,83}{2} + 0,92 \approx 1,34.$$

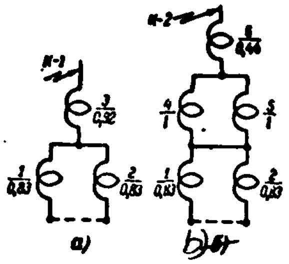

Fig. 6-8. Replacement schemes for example of 6-1.

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We determine resulting resisting of circuit to point K-2.

We accept the same base line power $S_б = 100$ MVA; therefore relative base line resistance of the generators remains constant/invariable ones, i.e., $x_1=x_2=0.83$.

Relative base line resisting of transformers we determine, utilizing formula (6-19):

$$x_4 = x_5 = \frac{u_к\% S_б}{100 S_{т.ном}} = \frac{7,5}{100} \cdot \frac{100}{7,5} = 1.$$

Relative base line resisting of electric power line according to formula (6-21):

$$x_6 = \frac{S_б x}{U_{ср}^2} = \frac{100 \cdot 0,4 \cdot 15}{37^2} \approx 0,44.$$

Converting diagram in Fig. 6-8b, we obtain:

$$x_{*\,рез\,K-2} = \frac{x_3}{2} + \frac{x_4}{2} + x_6 = \\ = \frac{0,83}{2} + \frac{1}{2} + 0,44 \approx 1,4.$$

The examined example shows that per unit calculation somewhat simpler, since for the larger part of network elements are usually known relative nominal resisting.

Some indications in accordance with the conversion of replacement schemes. During the computation resulting resisting of short circuit always one should approach simplification in the replacement scheme. Frequently the replacement schemes are symmetrical with respect to the point of short circuit, which makes it possible to connect the points of equal voltages and thereby to considerably simplify diagram and computation $x_{рез}$. For example, it is required to determine $x_{рез}$ for point K of diagram on Fig. of 6-9a with identical generators and step-up transformers. In this case during short circuit at point K the voltage on the busbars of sections A and B will be identical and through the sectional reactor P the short-circuit current flow/occur/last will not be. Because of this in replacement scheme sectional reactor it is possible not to consider and to connect directly points A and B, as shown in Fig. 6-9b.

Determination $x_{рез}$ for the similar case to us is already known.

With different generators (Fig. of 6-9a) the voltages on the busbars of sections A and B during short circuit at point K will not be equal and through the reactor will flow/occur/last the short-circuit current. Replacement scheme takes the form, shown in Fig. 6-10a. Determination $x_{рез}$ becomes complicated, since in diagram appears the triangle of resisting, formed by transformers and sectional reactor. For determination $x_{рез}$ it is necessary the triangle of resisting to replace with equivalent star of resisting.

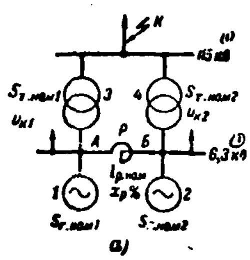

Fig. 6-9. Network of stations with the reacted composite busbars of generator voltage (a) and replacement scheme (b) for the point of the short circuit K with identical generators and transformers.

Key: (1). kV.

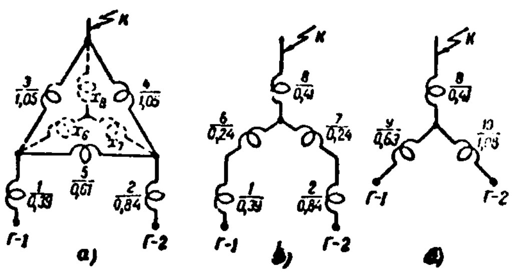

Fig. 6-10. Replacement schemes for point of short circuit K of network in Fig. 6-9 with different generators.

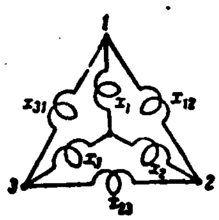

Fig. 6.11.

Fig. 6-11. Conversion of triangle of resisting into equivalent star of resisting.

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It is known that resisting x_1, x_2 and x_3 of triradial star, equivalent to the triangle of resisting x_{12}, x_{23} and x_{31} (Fig. 6-11), are equal to:

$$\left.\begin{aligned} x_1 &= \frac{x_{12}x_{31}}{x_{12}+x_{23}+x_{31}}; \\ x_2 &= \frac{x_{12}x_{23}}{x_{12}+x_{23}+x_{31}}; \\ x_3 &= \frac{x_{23}x_{31}}{x_{12}+x_{23}+x_{31}}. \end{aligned}\right\} \qquad (6\text{-}24)$$

If necessary it is possible the triradial star of resisting to replace with equivalent triangle of resisting which are determined from the formulas:

$$\left.\begin{aligned} x_{12} &= x_1 + x_2 + \frac{x_1 x_2}{x_3}; \\ x_{23} &= x_2 + x_3 + \frac{x_2 x_3}{x_1}; \\ x_{31} &= x_1 + x_3 + \frac{x_1 x_3}{x_2}. \end{aligned}\right\} \qquad (6\text{-}25)$$

Example of 6-2. To determine $x_{*\text{рез}}$ to point K of network in Fig. 6-9.

It is known:

$$S_{г.ном\,1} = 31,25 \text{ Мва}^{(1)};\ x''_{*d1} = 0,123;$$
$$S_{г.ном\,2} = 15 \text{ Мва}^{(1)};\ x''_{*d2} = 0,126;$$
$$I_{р.ном} = 1,5 \text{ ка}^{(2)};\ x_р = 10\%;$$
$$S_{т.ном\,1} = S_{т.ном\,2} = 10 \text{ Мва}^{(1)};\ u_к = 10,5\%.$$

Key: (1). MVA. (2). kA.

Medium nominal voltages are shown in the diagram.

Replacement scheme is given in Fig. 6-10a.

We lead all resisting to base line power $S_б = 100$ MVA:

$$x_1 = x''_{*d1} \frac{S_б}{S_{г.ном\,1}} = 0,123 \frac{100}{31,25} \approx 0,39;$$

$$x_2 = 0,126 \frac{100}{15} = 0,84;$$

$$x_3 = x_4 = \frac{u_к\% S_б}{100 S_{т.ном}} = \frac{10,5}{100} \cdot \frac{100}{10} = 1,05;$$

$$x_5 = \frac{x_р\%}{100} \frac{I_б}{I_{р.ном}} = \frac{10}{100} \cdot \frac{9,2}{1,5} = 0,61.$$

Here $I_б = \frac{100}{\sqrt{3} \cdot 6,3} \approx 9,2$ kA is determined with the voltage of that step/stage, on which is established/installed sectional reactor, i.e., with $U_б = 6,3$ kV.

We replace resisting of triangle x_3, x_4 and x_5 by equivalent star (Fig. 6-10b):

$$x_6 = x_7 = \frac{1,05\cdot 0,61}{1,05+1,05+0,61} = \frac{0,61}{2,71} \approx 0,24;$$

$$x_8 = \frac{1,05\cdot 1,05}{2,71} = 0,41.$$

Resisting x_1 and x_6 are connected in series:

$$x_9 = x_1 + x_6 = 0,39 + 0,24 = 0,63;$$

the same resisting x_2 and x_7:

$$x_{10} = x_2 + x_7 = 0,84 + 0,24 = 1,08.$$

Then replacement scheme takes the form, shown in Fig. 6-10c.

After connecting the neutrals of generators G-1 and G-2, we determine resulting resisting of short circuit:

$$x_{*\,\text{рез}} = \frac{x_9 x_{10}}{x_9 + x_{10}} + x_8 =$$
$$= \frac{0,63\cdot 1,08}{0,63+1,08} + 0,41 = 0,81.$$

6.5. Short circuit in the circuit, which feeds from the electrical system of the unlimited power.

The electrical system of the unlimited power conditionally is considered such relatively powerful/thick system, voltage on busbars of which can be virtually considered constant/invariable with any changes in the current (even during short circuit) in connected to it low-power circuit ($S_{\text{c.ном}} = \infty$; $x_c = 0$; $r_c = 0$). In actuality the power of electrical systems and their resisting have some finite values.

However, many elements/cells of electrical networks possess this small power in comparison with the power of their feeding system and this considerable resisting in comparison with resisting of system, that during short circuits after such elements/cells (transformer, reactor, line) the voltage on the busbars of the feeding system changes insignificantly and frequently without special miscalculation of short-circuit current this change in the voltage it is possible not to consider.

During the computation of short-circuit currents for the selection of electrical equipment it is possible not to consider resistance of the feeding system, if it does not exceed 5-10o/o resulting (or calculation) resisting of short circuit. Obtained in this case corresponding exaggeration of short-circuit current does not usually affect the types of the adjustable electrical equipment.

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Let us examine the process of changing the short-circuit current in the simplest circuit (Fig. 6-12), which feeds from the electrical system of the unlimited power. let us consider that the voltage on the busbars of system is equal to medium voltage U_{cp} of the corresponding electrical step/stage, and resisting are expressed in ohms and are given to the same voltage U_{cp}.

The current of load in normal mode is determined by the value of voltage U_{cp} and by the values of resisting of network/grid z_{pes} and electrical receivers $z_{н}$.

During three-phase short circuit at point K resisting of circuit sharply decreases to values z_{pes}, which is considerably less than resisting of electrical receivers $z_{н}$. the circuital current increases of up to the value, caused by voltage on the busbars of system U_{cp} and resulting resisting of circuit of ~~up~~ z_{pes} to the place of short circuit.

It is known that in the circuits, which contain inductance, it cannot be an instantaneous change in the current. Any change of resisting the circuit causes the transient process, during which the circuital current changes to certain steady value. A similar transient process occurs, also, during short circuits.

Fig. 6-13 gives the curve of a change of the short-circuit current $i_{к}$ in the circuit, shown in Fig. 6-12. There it is shown that this current can be decomposed on two component/term: the forced harmonic current, which has the steady value, and the free aperiodic current, which damps exponentially. From theoretical electrical

engineering it is known that the same change in the current and its component/term occurs in the circuit, which contains L and r, upon its inclusion/connection to sine voltage.

In the practical calculations of short-circuit currents accept forced periodic component/term of short-circuit current, which in this case is the steady current, to call periodic component/term of short-circuit current (or, it is shorter, by periodic current). For it usually take the following designations: instantaneous value $i_{п}$, amplitude value $I_{п.м}$, effective value $I_{п}$.

The effective value of the steady short-circuit current is in general accept to designate I_{∞}, therefore in the examined/considered by us special case of short circuit $I_{\infty}=I_{п}$.

Free aperiodic component/term of short-circuit current is conventionally designated as in abbreviated form aperiodic component/term of short-circuit current (or even by aperiodic current). For it are accepted the designations: instantaneous value $i_{а}$, initial value $i_{а(t=0)}$, great initial value $I_{а.м}$.

The value of periodic of component/term of the current of three-phase short circuit is determined by voltage on the busbars of system and resisting of short circuit.

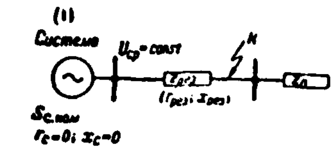

Fig. 6-12. Circuit diagram, which feeds from the system of the unlimited power.

Key: (1). System.

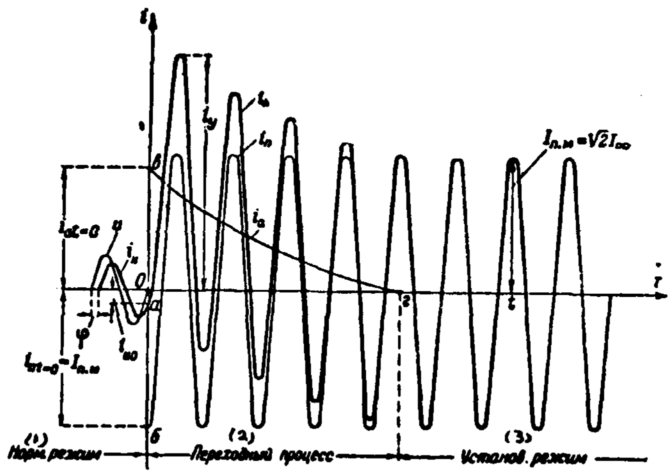

Fig. 6-13. curve of change of short-circuit current in circuit, which feeds from system of unlimited power.

Key: (1). N. mode/conditions. (2). Transient process. (3). steady conditions.

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Since the voltage indicated remains constant/invariable during entire process of short circuit, then constant/invariable remains the effective value of periodic component/term of short-circuit current, determined according to the law of the ohm:

$$I_{\text{п}}^{(3)}=\frac{U_{\text{ср}}}{\sqrt{3}\,z_{\text{рез}}}. \qquad (6\text{-}26)$$

where $U_{\text{ср}}$ - a voltage on the busbars of feeding system, kV;

$z_{\text{рез}}$ - resulting impedance of short circuit, led to $U_{\text{ср}}$, ohm.

In settings up by voltage is above 1000 V usually $r_{\text{рез}} \ll x_{\text{рез}}$, therefore periodic component/term of short-circuit current can be determined approximately by the formula:

$$I_{\text{п}}^{(3)}=\frac{U_{\text{ср}}}{\sqrt{3}\,x_{\text{рез}}}, \qquad (6\text{-}27)$$

where $x_{\text{рез}}$ - resulting inductive reactance of circuit, led to $U_{\text{ср}}$, ohm.

The same value of periodic of component/term of the current of three-phase short circuit can be determined, also, through resisting of circuit in relative unity. If we from formula (6-22) determine value $x_{\text{рез}}$ and to substitute it into formula (6-27), then after simple conversions we will obtain:

$$\frac{I_{\text{п}}^{(3)}}{I_{б}}=\frac{\frac{U_{\text{ср}}}{U_{б}}}{x_{*\text{рез}}},$$

where

$$\frac{I_{\text{п}}^{(3)}}{I_{б}}=I_{*\text{п}}^{(3)}.$$

Since $U_{б}=U_{\text{ср}}$, then

$$I_{*\text{п}}^{(3)}=\frac{1}{x_{*\text{рез}}} \qquad (6\text{-}28)$$

or in the kiloamperes

$$I_{\text{п}}^{(3)}=I_{*\text{п}}^{(3)}I_{б}=\frac{I_{б}}{x_{*\text{рез}}}, \qquad (6\text{-}29)$$

where $I_{б}=\frac{S_{б}}{\sqrt{3}U_{б}}$ - base line current, determined when U equal to $U_{\text{ср}}$ to that electrical step/stage for which is designed the short-circuit current, kA;

$x_{*\text{рез}}$- resulting relative base line resisting of short circuit, calculated at base line power accepted.

If periodic component/term must be determined taking into account the effective resistance of circuit, then into formula (6-29) instead of $x_{*\text{рез}}$ one should substitute $z_{*\text{рез}}$.

From formula (6-29) it is evident that the results of computation $I_{\text{п}}^{(3)}$ do not depend on accepted in calculation base line power $S_{б}$, since with its change directly proportionally change both

$I_{б}$, and $x_{*рез}$. However, concerning relative values of periodic of component/term, determined according to formula (6-28), then its value depends on the base line power accepted.

Let us pass to the examination by aperiodic by component/term of short-circuit current. It was above indicated that in the circuits of high voltage the effective resistance were small and virtually they do not affect the value of periodic of component/term of current. Therefore in the majority of the cases value by periodic by component/term is determined without taking into account the effective resistance of circuit by formulas (6-27 and 6-29). In this case it is possible to consider that periodic component/term of current is current almost purely inductive.

At the same time in the examination by aperiodic by component/term of short-circuit current i_a one cannot fail to consider the effective resistance of circuit, since if we place it equal to zero, then aperiodic current attenuate will not be, which will distort the real picture of a change in the short-circuit current. Therefore in the examination of change in the time of aperiodic current the effective resistance of circuit one must take into account.

Short circuit is possible at any moment of time at any

instantaneous value of voltage. In circuits with purely inductive reactance ($r_{рез}=0$), but approximately also in circuits with relatively low effective resistance ($r_{рез} < x_{рез}$), heaviest case of short circuit as this will be shown below, is short circuit at moment/torque, when the instantaneous value of voltage is equal to zero. Given Fig. 6-13 curves gives for the case when at the moment of short circuit the instantaneous value of voltage u on the busbars of system was equal to zero, and the current of load had instantaneous value $i_{н0}$.

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If periodic component/term of short-circuit current is is approximately considered the as purely inductive current, then during short circuit at the moment of time indicated the initial instantaneous value of periodic of component/term must be equal to its amplitude value $i_{п t=0}=I_{п.м}$ (Fig. 6-13), i.e., circuital current at the moment of short circuit must instantly change from value $i_{н0}$ (cut 0a), to value $I_{п.м}$ (cut 0b).

Respectively must change the magnetic flux of circuit. In actuality in the circuit, which possesses inductance, it cannot occur an instantaneous change in the magnetic flux and, consequently, also current, since with a change of the magnetic flux in circuit is induced emf, which calls the course of countercurrent - free

aperiodic current. As a result of imposition of both components at the moment of short circuit the circuital current does not change and remains equal to the instantaneous value of the current of load $i_{н0}$.

From the aforesaid it follows that the initial value of aperiodic of component/term of short-circuit current is equal

$$i_{a\,t=0} = i_{н0} - I_{п.м}. \quad (6\text{-}30)$$

Further aperiodic component/term attenuates on exponential to the law:

$$i_a = i_{a\,t=0} e^{-\frac{t}{T_a}}, \quad (6\text{-}31)$$

where T_a - constant of time of the attenuation of aperiodic of component/term.

Time constant T_a is determined from the formula:

$$T_a = \frac{L_{к.ц}}{r_{к.ц}} = \frac{x_{рез}}{314 r_{рез}}, \quad (6\text{-}32)$$

where $L_{к.ц}$, $r_{к.ц} = r_{рез}$ and $x_{рез}$ - inductance and active and inductive reactances of the short-circuited circuit (or $r_{*рез}$ and $x_{*рез}$).

In circuits with voltage above 1000 V with relatively low effective resistance average/mean value T_a is approximately/exemplarily 0.05 s; therefore the duration of the attenuation of aperiodic of component/term does not usually exceed

0.2 s. In circuits with high effective resistance aperiodic component/term attenuates more rapidly.

After the attenuation of aperiodic of component/term concludes the transient process of short circuit and begins the steady mode/conditions. In circuit flows/occurs/lasts steady current $I_{\infty}=I_{н}$. Frequently it the designate $I_{к}$.

If short circuit occurs at this moment of time when the initial instantaneous value of periodic of component/term of current proves to be equal to $i_{н0}$ (with u≠0), i.e., $i_{п\,t=0}=i_{н0}$, then the initial value of aperiodic of component/term proves to be equal to zero $i_{а\,t=0}=0$ (at the moment of short circuit circuital current it does not change), as a result of which aperiodic component/term in short-circuit current is absent.

But if to short closing a circuit ran idle ($I_{н}=0$) and short circuit occurred at moment/torque u=0, then $i_{п\,t=0}=I_{п.м}$ and the initial value of aperiodic of component/term is obtained greatest: $i_{а\,t=0}=I_{а.м}=-I_{п.м}$. This condition is calculation, since in this case short-circuit current $i_{к}$ in circuit has great value.

Examining the curve of short-circuit current (Fig. 6-13), we see that through half-period (0.01 s) the instantaneous value of

short-circuit current attains maximum value, which is called impact short-circuit current and designate i_y (current, which generates the greatest mechanical actions).

According to the same curves

$$i_y = I_{\text{п.м}} + i_{\text{a}\,t=0,01}.$$

Let us determine the great value of impact current under design conditions indicated above.

From equation (6-31)

$$i_{\text{a}\,t=0,01} = I_{\text{a.м}} e^{-\frac{0,01}{T_a}}.$$

At the moment of impact current (t=0.01 s) periodic and aperiodic component/term have identical direction; therefore it is possible to write:

$$i_y = I_{\text{п.м}} + I_{\text{a.м}} e^{-\frac{0,01}{T_a}} = I_{\text{п.м}} + I_{\text{п.м}} e^{-\frac{0,01}{T_a}} = $$
$$= (1 + e^{-\frac{0,01}{T_a}}) I_{\text{п.м}}.$$

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However, since

$$I_{\text{п.м}} = \sqrt{2} I_{\text{п}},$$

that

$$i_y = (1 + e^{-\frac{0.01}{T_a}})\sqrt{2} I_n = k_y \sqrt{2} I_n.$$

Value

$$k_y = 1 + e^{-\frac{0.01}{T_a}} \qquad (6\text{-}33)$$

is called the impact coefficient of short-circuit current. Introducing impact coefficient, finally we obtain:

$$i_y = k_y \sqrt{2} I_n. \qquad (6\text{-}34)$$

Value I_n is determined from formula (6-27) or (6-29).

Since in formula (6.34) value $\sqrt{2} I_n$— the amplitude of periodic of component/term of short-circuit current, then impact coefficient k_y. considers the participation of aperiodic of component/term in the formation of impact current.

Let us determine the possible limiting values of impact coefficient k_y. Since $T_a = \frac{x_{pes}}{314 r_{pes}}$, then:

if circuit it possesses only inductive reactance ($r_{pes} = 0$), then $T_a = \infty$ and $k_y = 2$, aperiodic component/term of short-circuit current it does not attenuate;

if circuit it possesses only effective resistance ($x_{pes} = 0$), then

$T_a=0$ and $k_y=1$, aperiodic component/term in no way it appears.

Thus, $2>k_y>1$.

In the circuits of settings up by voltage is above 1000 V with predominant inductive reactance average/mean value $T_a\approx 0{,}05$ s and $k_y=1{,}8$, with this

$$i_y=1{,}8\sqrt{2}I_n=2{,}55I_n. \qquad (6\text{-}35)$$

During the calculation of short-circuit current taking into account the effective resistance of circuit should be calculated the value of impact coefficient in formula (6-33), after determining the preliminarily time constant of circuit by formula (6-32).

In Fig. 6-14 are given curves [6-1] of dependence $e^{-\frac{t}{T_a}}=f(t;\ T_a)$, that make it possible to rapidly determine the instantaneous value of aperiodic of component/term depending on T_a (value $e^{-\frac{t}{T_a}}=a_t$ is called the attenuation factor of aperiodic of component/term). On curved t=0.01 s it is possible to determine value $a_{t=0{,}01}$, and then impact coefficient in formula (6-32).

During estimates of impact current on the side of the secondary voltage of the transformers whose power do not exceed 1000 kVA in each of the in parallel working transformers, it is possible to

accept $k_y = 1{,}3$.

Full/total/complete short-circuit current during transient process is not sinusoidal as a result of the presence aperiodic component/term. Therefore effective value full current $I_{кt}$ for certain moment/torque time t after the beginning of short circuit defines as root-mean-square current during the period (0.02 s), in middle of which is located the moment/torque of time t:

$$I_{кt} = \sqrt{I_п^2 + I_{аt}^2}. \qquad (6\text{-}36)$$

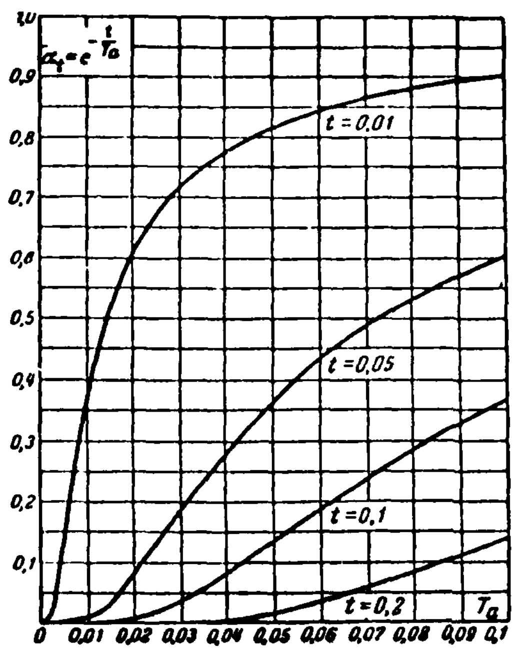

Fig. 6-14. Curves for determining the attenuation factor of aperiodic of component/term of short-circuit current.

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The effective value of aperiodic of component/term of short-circuit current during a period approximately can be taken as the equal to its instantaneous value in the middle of period, i.e., by considering that during period aperiodic component/term does not change and has value i_{at}. Then formula (6-36)

can be rewritten thus:

$$I_{ud} = \sqrt{I_n^2 + i_{at}^2}. \quad (6\text{-}37)$$

Using latter/last formula, let us determine effective value of full of short-circuit current for first period after the onset of the short circuit:

$$I_y = \sqrt{I_n^2 + i_{at=0,01}^2}.$$

Since $i_{at=0,01} = (k_y - 1)\sqrt{2} I_n$, then after conversions we obtain:

$$I_y = I_n \sqrt{1 + 2(k_y - 1)^2}. \quad (6\text{-}38)$$

With the impact coefficient $k_y = 1,8$

$$I_y = 1,52 I_n \quad (6\text{-}39)$$

and

$$\frac{i_y}{I_y} = \frac{1,8\sqrt{2} I_n}{1,52 I_n} = 1,68. \quad (6\text{-}40)$$

The great value of relation $\frac{i_y}{I_y} = 1,73$ is obtained with impact coefficient $k_y = 1,5$.

In three-phase circuit at the moment of three-phase short circuit the instantaneous values or voltages in phases are different, in consequence of which different the initial values of periodic and aperiodic of component/term and, consequently, also the full/total/complete values of short-circuit currents in phases. If three-phase short circuit occurred at moment/torque, when in one of phases $i_{a\,t=0} = I_{a.m}$, then in two other phases $i_{a\,t=0}$ will be less $I_{a.m}$.

Therefore only in one phase impact current can have computed value, determined according to formula (6-34). The aforesaid illustrate curves to Fig. 6-15, led for the case when to short closing a circuit was not loaded ($I_н=0$) and at the moment of short circuit the instantaneous value of the voltage of phase A was equal to zero ($u_A=0$).

As can be seen from curves in Fig. 6-15, the amplitudes of periodic of component/term in all phases are identical, since their value is determined by voltage U_{cp} on the busbars of the feeding system and resulting resisting of short-circuited circuit $x_{рез}$. Aperiodic component/term in phases are different, since their values depend on the moment/torque of short circuit, i.e., from value $i_{н\,t=0}$.

Impact currents in phases not are only different by value, but they do not coincide also in time.

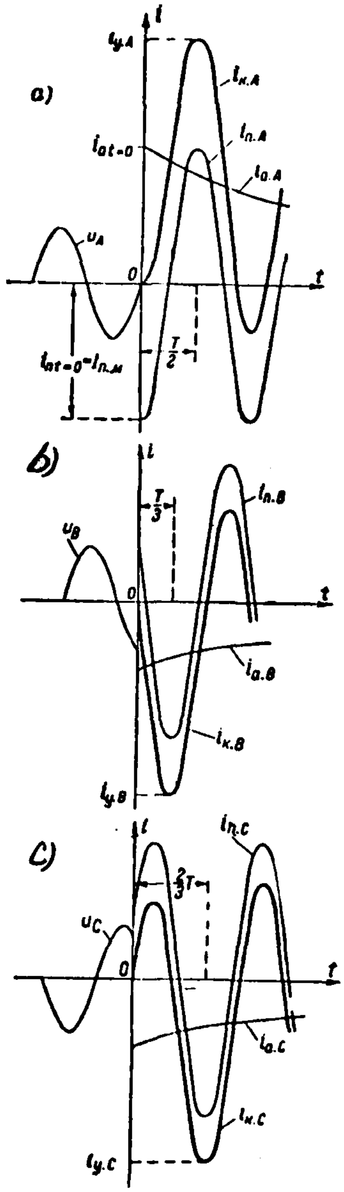

Fig. 6-15. Currents in phases during three-phase short closing a circuit, which feeds from the source of the unlimited power.

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When selecting of switches according to the disconnecting ability they use also the amount of the power of short circuit, determined by usual expression for the three-phase power:

$$S_{\kappa}=\sqrt{3}\,U_{cp}I_{n},\qquad (6\text{-}41)$$

where U_{cp} - medium nominal voltage of that electrical step/stage, for which is calculated current I_{n}.

The power of short circuit is the value of conditional, since during its determination they accept the medium nominal voltage of the step/stage of short circuit.

If left and the right side of formula (6-29) are multiplied on $\sqrt{3}$ and U_{cp}, then we will obtain (assuming/setting $U_{6}=U_{cp}$):

$$S_{\kappa}=\frac{S_{6}}{x_{*pe3}}.\qquad (6\text{-}42)$$

Example of 6-3. To calculate impact and steady currents and power of short circuit at the points, indicated on network in Fig. 6-16a, where are given all data, necessary for calculation. The

cables of line 6 kV, feeding distribution point RP, work in parallel. The effective resistance of cables 6 kV must be taken into consideration.

Since short-circuit currents are determined only during three-phase short circuit, the index (3) for simplification in the recordings it is omitted.

Let us fulfill calculations in two versions, expressing ohmages and relative unity.

Version 1. All resisting we express in ohms with the medium voltage of that step/stage, on which occurred certain closing/shorting.

Short-circuit current, which flows into point K-1. In this case $U_б = U_{cp1} =$ 115 kV resisting of circuit to the point of the short circuit K-1 is equal to resisting of air electric power line, i.e.

$$x_{рез\ K\text{-}1} = x_1 = lx = 70 \cdot 0{,}4 = 28 \overset{(1)}{\text{ом.}}$$

Key: (1). ohm.

According to formula (6-27):

$$I_{п\,K\text{-}1} = I_{\infty\,K\text{-}1} = \frac{U_{ср\,1}}{\sqrt{3}\,x_{рез\,K\text{-}1}} = \frac{115}{\sqrt{3}\cdot 28} \approx 2{,}4 \ ка.^{(1)}$$

Key: (1). kA.

Impact current according to formula (6-35):

$$i_{y\,K\text{-}1} = 1{,}8\sqrt{2}\,I_{п\,K\text{-}1} = 2{,}55\cdot 2{,}4 \approx 6 \ ка.^{(1)}$$

Key: (1). kA.

Power of short circuit according to formula (6-41):

$$S_{K\text{-}1} = \sqrt{3}\,U_{ср\,1} I_{п\,K\text{-}1} = \sqrt{3}\cdot 115\cdot 2{,}4 \approx 480 \ Мва.^{(1)}$$

Key: (1). MVA.

Replacement scheme for the calculation of short-circuit currents at the secondary voltage of substation (at points K-2, K-3 and K-4) is given in Fig. 6-16b. We compute ohmages of all elements/cells of replacement scheme with voltage $U_б = U_{ср\,2} = 6{,}3$ kV.

Resisting of air electric power line, led to voltage $U_{ср\,2}$:

$$\overset{*}{x}_1 = x_1 \frac{U_{ср\,2}^2}{U_{ср\,1}^2} = 28\,\frac{6{,}3^2}{115^2} \approx 0{,}08 \ ом.^{(1)}$$

Key: (1). ohm.

Resisting of transformer we determine, being guided by formula (6-5) when $U_{т.ном} = U_{ср\,2}$:

$$x_2 = x_3 = x_4 = \frac{u_к\%}{100}\frac{U^2_{т.ном}}{S_{т.ном}} = \frac{10,5}{100}\cdot\frac{6,3^2}{15} = 0,28 \text{ ом.}^{(1)}$$

Key: (1). ohm.

Resisting of reactor we determine, being guided formula (6-4), accepting $U_{р.ном} = U_{ср}$:

$$x_5 = \frac{x_р\%}{100}\frac{U_{р.ном}}{\sqrt{3}I_{р.ном}} = \frac{4\cdot 6,3}{100\sqrt{3}\cdot 0,3} = 0,48 \text{ ом.}^{(1)}$$

Key: (1). ohm.

Inductive reactance of cable we accept from calculation 0.08 Ω/km (see §6-3):

$$x_6 = x_7 = 0,08\cdot 2,5 = 0,2 \text{ ом.}^{(1)}$$

Key: (1). ohm.

The effective resistance of cable according to formula (6-15):

$$r_6 = r_7 = \frac{l\,1\,000}{\gamma s} = \frac{2,5\cdot 1\,000}{53\cdot 70} = 0,67 \text{ ом.}^{(1)}$$

Key: (1). ohm.

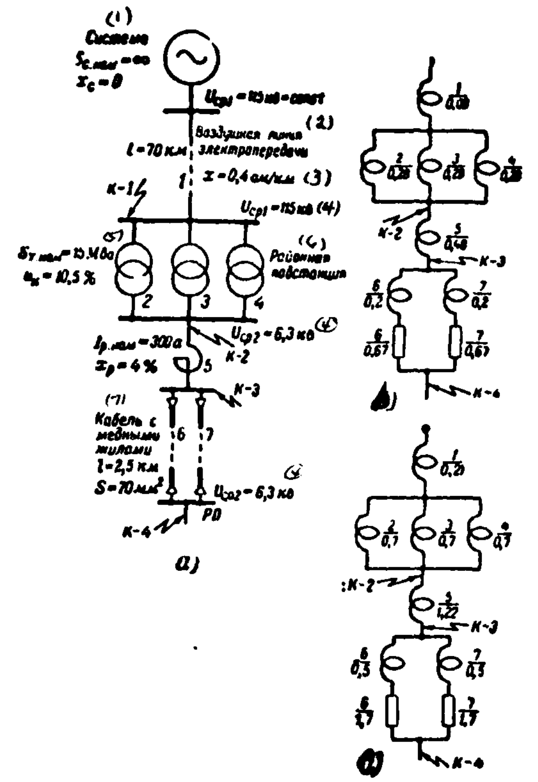

Fig. 6-16. Network (a) and replacement scheme (b) for example of 6-3.

Key: (1). System. (2). Overhead electric power line. (3). Ω/km. (4). kV. (5). MVA. (6). working substation. (7). Cable with copper veins/strands.

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Short-circuit current, which flows into point K-2. Resulting

resistance of the circuit

$$x_{\text{рез}\,K\text{-}2} = \dot{x}_1 + \frac{x_2}{3} = 0{,}08 + \frac{0{,}28}{3} \approx 0{,}17 \overset{(1)}{\text{ом}}.$$

Key: (1). ohm.

Then:

$$I_{n\,K\text{-}2} = I_{\infty\,K\text{-}2} = \frac{U_{\text{ср}\,2}}{\sqrt{3}\,x_{\text{рез}\,K\text{-}2}} = \frac{6{,}3}{\sqrt{3}\cdot 0{,}17} \approx 21 \overset{(1)}{\text{ка}};$$
$$i_{y\,K\text{-}2} = 2{,}55\cdot 21 \approx 54 \text{ ка}; (1)$$
$$S_{K\text{-}2} = \sqrt{3}\cdot 6{,}3\cdot 21 = 230 \text{ Мва}. (2)$$

Key: (1). κA. (2). MVA.

Short-circuit current, whicn flows in K-3. Resulting resisting of the circuit

$$x_{\text{рез}\,K\text{-}3} = x_{\text{рез}\,K\text{-}2} + x_5 = 0{,}17 + 0{,}48 = 0{,}65 \overset{(1)}{\text{ом}}.$$

Key: (1). ohm.

Then:

$$I_{n\,K\text{-}3} = I_{\infty\,K\text{-}3} = \frac{6{,}3}{\sqrt{3}\cdot 0{,}65} \approx 5{,}6 \overset{(1)}{\text{ка}};$$
$$i_{y\,K\text{-}3} = 2{,}55\cdot 5{,}6 \approx 14 \text{ ка}; (1)$$
$$S_{K\text{-}3} = \sqrt{3}\cdot 6{,}3\cdot 5{,}6 \approx 61 \text{ Мва}.^{(2)}$$

Key: (1). kA. (2). MVA.

Short-circuit current, which flows into point K-4. Resulting resisting of circuit we determine taking into account active and inductive reactance of the cables:

$$x_{\text{рез}\,K\text{-}4}=x_{\text{рез}\,K\text{-}3}+\frac{x_{\text{в}}}{2}=0,65+\frac{0,2}{2}=0,75\ \text{ом};^{(1)}$$

$$r_{\text{рез}\,K\text{-}4}=\frac{r_{\text{в}}}{2}=\frac{0,67}{2}\approx 0,34\ \text{ом}.^{(1)}$$

Key: (1). ohm.

In this case $\frac{r_{\text{рез}\,K\text{-}4}}{x_{\text{рез}\,K\text{-}4}}=\frac{0,34}{0,75}>\frac{1}{3}$, therefore the effective resistance of cables must be taken into consideration.

$$z_{\text{рез}\,K\text{-}4}=\sqrt{r^2_{\text{рез}\,K\text{-}4}+x^2_{\text{рез}\,K\text{-}4}}=$$
$$=\sqrt{0,34^2+0,75^2}\approx 0,82\ \text{ом}.^{(1)}$$

Key: (1). ohm.

Short-circuit current

$$I_{\text{п}\,K\text{-}4}=I_{\infty\,K\text{-}4}=\frac{U_{\text{ср}}}{\sqrt{3}\,z_{\text{рез}\,K\text{-}4}}=$$
$$=\frac{6,3}{\sqrt{3}\cdot 0,82}\approx 4,4\ \text{ка}.\ ^{(1)}$$

Key: (1). kA.

We determine the time constant of circuit by formula (6-32):

$$T_a=\frac{x_{\text{рез}\,K\text{-}4}}{314\,r_{\text{рез}\,K\text{-}4}}=\frac{0,75}{314\cdot 0,34}=0,007.$$

On curve on Fig. 6-14 we find $a_{t=0,01}=0,25$.

Impact coefficient $k_y = 1 + 0{,}25 = 1{,}25.$

Impact current $i_{y\,K\text{-}4} = k_y \sqrt{2} I_{n\,K\text{-}4} = 1{,}25\sqrt{2} \cdot 4{,}4 \approx 7{,}8$ kA.

Power of the short circuit

$$S_{K\text{-}4} = \sqrt{3} \cdot 6{,}3 \cdot 4{,}4 \approx 48 \overset{(1)}{\text{Мва.}}$$

Key: (1). MVA.

Version 2. All resisting we express in relative units. Full/total/complete replacement scheme is given in Fig. 6-16c. We accept base line power $S_б = 100$ MVA and we lead to it all relative resisting of replacement scheme.

Relative base line inductive reactance of electric power line according to formula (6-21)

$$x_1 = x_{*\,л.б} = x_л \frac{S_б}{U^2_{ср\,I}} = 0{,}4 \cdot 70 \cdot \frac{100}{115^2} = 0{,}21;$$

the same of transformer according to formula (6-19)

$$x_2 = x_3 = x_4 = x_{*\,т.б} = x_{*т} \frac{S_б}{S_{т.ном}} =$$

$$= \frac{10{,}5}{100} \cdot \frac{100}{15} = 0{,}7;$$

the same of reactor according to formula (6-20)

$$x_5 = x_{*\,р.б} = x_{*\,р.ном}\frac{I_б}{I_{р.ном}} = \frac{4}{100}\cdot\frac{9,2}{0,3} = 1,22,$$

where

$$I_б = \frac{S_б}{\sqrt{3}\,U_б} = \frac{100}{\sqrt{3}\cdot 6,3} \approx 9,2 \overset{(1)}{ка.}$$

Key: (1). kA.

Inductive reactance of cable we accept from calculation 0.08 Ω/km (see §6-3). Relative base line inductive reactance of the cable

$$x_6 = x_7 = 0,08\cdot 2,5\frac{100}{6,3^2} = 0,5.$$

The effective resistance of cable according to formula (6-15):

$$r_{каб} = \frac{l\,1000}{\gamma s} = \frac{2,5\cdot 1\,000}{53\cdot 70} = 0,674 \overset{(1)}{ом.}$$

Key: (1). ohm.

Relative base line effective resistance of the cable

$$r_6 = r_7 = 0,674\frac{100}{6,3^2} = 1,7.$$

Short-circuit current, which flows into point K-1. We accept $U_б = 115$ kV, then

$$I_б = \frac{S_б}{\sqrt{3}U_б} = \frac{100}{\sqrt{3}\cdot 115} = 0,5 \overset{(1)}{ка.}$$

Key: (1). kA.

In this case

$$x_{*рез\,K\text{-}1} = x_1 = 0,21.$$

According to formula (6-29):

$$I_{n\,K\text{-}1} = I_{\infty\,K\text{-}1} = \frac{I_б}{x_{*рез\,K\text{-}1}} = \frac{0,5}{0,21} \approx 2,4 \overset{(1)}{ка.}$$

Key: (1). kA.

Impact current according to formula (6-35):

$$i_{y\,K\text{-}1} = 1,8\sqrt{2}\,I_{n\,K\text{-}1} = 2,55 \cdot 2,4 \approx 6 \overset{(1)}{ка.}$$

Key: (1). kA.

Power of short circuit according to formula (6-42):

$$S_{K\text{-}1} = \frac{S_б}{x_{*рез\,K\text{-}1}} = \frac{100}{0,21} \approx 480 \overset{(1)}{Мва.}$$

Key: (1). MVA.

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Short-circuit current, which flows into point K-2. We accept $U_б = 6.3$ kV; then

$$I_б = \frac{100}{\sqrt{3} \cdot 6,3} \approx 9,2 \overset{(1)}{ка.}$$

Key: (1). kA.

Resulting resisting of the circuit

$$x_{*рез\,K\text{-}2} = x_1 + \frac{x_2}{3} = 0,21 + \frac{0,7}{3} \approx 0,44.$$

Then:

$$I_{\text{п} K\text{-}2} = I_{\infty K\text{-}2} = \frac{9,2}{0,44} = 21 \ \kappa a;^{(1)}$$
$$i_{y K\text{-}2} = 2,55 \cdot 21 = 54 \ \kappa a;^{(1)}$$
$$S_{K\text{-}2} = \frac{100}{0,44} \approx 230 \ M\mathit{ва}.^{(2)}$$

Key: (1). kA. (2). MVA.

Short-circuit current, which flows into point K-3. In this case

$$U_б = 6,3 \ \kappa в \ ^{(1)}\text{и} \ I_б = 9,2 \ \kappa a.^{(2)}$$

Key: (1). and. (2). kA.

Resulting resisting of the circuit

$$x_{*\text{рез} K\text{-}3} = x_{*\text{рез} K\text{-}2} + x_{*} = 0,44 + 1,22 = 1,66.$$

Then:

$$I_{\text{п} K\text{-}3} = I_{\infty K\text{-}3} = \frac{9,2}{1,66} \approx 5,6 \ \kappa a;^{(1)}$$
$$i_{y K\text{-}3} = 2,55 \cdot 5,6 \approx 14 \ \kappa a;^{(1)}$$
$$S_{K\text{-}3} = \frac{100}{1,66} \approx 60 \ M\mathit{ва}.^{(2)}$$

Key: (1). kA. (2). MVA.

Short-circuit current, which flows into point K-4.

$$U_б = 6,3 \ \kappa в^{(1)} \ \text{и} \ I_б = 9,2 \ \kappa a.^{(2)}$$

Key: (1). and. (2). kA.

Resulting resisting of the circuit:

$$r_{*\text{рез}\,K\text{-}4}=\frac{r_6}{2}=\frac{1,7}{2}=0,85;$$

$$x_{*\text{рез}\,K\text{-}4}=x_{*\text{рез}\,K\text{-}3}+\frac{x_6}{2}=1,66+\frac{0,5}{2}=1,91.$$

In this case $\frac{r_{*\text{рез}}}{x_{*\text{рез}}}=\frac{0,85}{1,91}>\frac{1}{3}$, therefore the effective resistance of cables must be taken into consideration.

$$z_{*\text{рез}\,K\text{-}4}=\sqrt{0,85^2+1,91^2}=2,1.$$

Short-circuit current

$$I_{п\,K\text{-}4}=I_{\infty\,K\text{-}4}=\frac{I_б}{z_{*\text{рез}\,K\text{-}4}}=\frac{9,2}{2,1}=4,4 \overset{(1)}{\text{ка}}.$$

Key: (1). kA.

We determine the time constant of circuit by formula (6-32):

$$T_a=\frac{x_{*\text{рез}}}{314r_{*\text{рез}}}=\frac{1,91}{314\cdot 0,85}=0,007.$$

On curve on Fig. 6-14 we find $\alpha_{t=0,01}=0,25.$

Impact coefficient $k_y=1+0,25=1,25.$

Impact current $i_{y\,K\text{-}4}=k_y\sqrt{2}I_{п\,K\text{-}4}=1,25\sqrt{2}\cdot 4,4\approx 7,8$ kV.

Power of the short circuit

$$S_{K-4} = \frac{100}{2,1} = 48 \overset{(1)}{Mea},$$

Key: (1). MVA.

As one would expect, calculation by both methods gives completely identical results.

From the comparison of the values of currents and power during short circuits at points K-2 and K-3 evidently, how sharply reactor on line decreases current and power of short circuit.

Calculation under the condition of the unlimited power of the feeding system makes it possible to determine the limiting possible values of short-circuit currents in this setting up, which is especially important, if not precise indications about further development of system. The selection of electrical equipment in terms of these values of short-circuit currents gives guarantee in the fact that during any development of system the designed setting up it is not necessary to re-equip, since at any power of system the actual values of short-circuit currents in setting up will be less than calculations.

The aforesaid can be explained based on the example of diagram in Fig. 6-16. For example, short-circuit current at point K-1 can be

more than calculated only during the construction of the second parallel feeding line. Short-circuit current at point K-2 can exceed calculation only during setting up on the substation of the supplementary in parallel connected transformers or during the replacement of those established/installed more powerful/thick.

In the practice of dasign and operation frequently it is to necessary rapidly calculate maximally possible short-circuit current after any network element - by power transformer, reactor, etc. in this case they enter as follows.

Let us assume resistive of xo/o for which are known its rating factors $S_{ном}$, $I_{ном}$, $U_{ном}$. Let us agree that during short circuit at point K (Fig. 6-17) the voltage before resisting (from feeding side) remains constant/invariable and equal to the nominal voltage of resisting (condition of feed from the system of unlimited power).

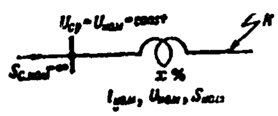

Fig. 6-17. Diagram to the determination of the maximum value of short-circuit current.

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Then it is possible to write

$$\frac{I_{к}}{I_{ном}}=\frac{100}{x\%}$$

(with course through the resistor/resistance of current $I_{ном}$ a voltage drop in it comprises $x\%$ and with the course of current $I_{к}$ a voltage drop composes 100o/o).

From latter/last expression we obtain:

$$I_{к}=I_{ном}\frac{100}{x\%}. \qquad (6\text{-}43)$$

Value 100/xo/o is called the greatest multiplicity of short-circuit current.

Multiplying left and the right side of formula (6-43) on $\sqrt{3}\,U_{ср}$ (under condition $U_{ном}=U_{ср}$), we obtain:

$$S_{к}=S_{ном}\frac{100}{x\%}. \qquad (6\text{-}44)$$

In connection with power transformer this formula takes the form:

$$S_{к}=S_{т.ном}\frac{100}{u_{к}\%} \qquad (6\text{-}45)$$

and

$$I_к=\frac{S_к}{\sqrt{3}U_{ср2}}, \qquad (6\text{-}46)$$

where $U_{ср2}$ - medium nominal voltage of the step/stage of the secondary side of transformer.

In the case of reactor when $U_{р.ном}=U_{ср}$ formula (6-43) takes the form:

$$I_к=I_{р.ном}\frac{100}{x_р\%}. \qquad (6\text{-}47)$$

Values $i_у$ and $I_у$ determine from the previously brought-out formulas.

For the air and cable lines whose resistor/resistance is usually known in ohms, • to more conveniently use the following formulas:

$$I_к=\frac{U_{ср}}{\sqrt{3}z_л} \qquad (6\text{-}48)$$

or, when $r_л=0$,

$$I_к=\frac{U_{ср}}{\sqrt{3}x_л}. \qquad (6\text{-}49)$$

Example of 6-4. To determine maximally possible current and

power of short circuit on the secondary side of the transformer in power 1800 kVA of its own needs of station. Impedance voltage $u_к = 8\%$; the primary voltage of the transformer of 6.3 kV, and secondary of 3.15 kV.

Power of the short circuit

$$S_к = S_{т.ном} \frac{100}{u_к\%} = 1.8 \frac{100}{8} \approx 23 \text{ } Мва.^{(1)}$$

Key: (1). MVA.

Short-circuit current

$$I_к = \frac{S_к}{\sqrt{3} U_{ср}} = \frac{23}{\sqrt{3 \cdot 3.15}} \approx 4.2 \text{ } ка;^{(1)}$$
$$i_у = 2.55 \cdot 4.2 \approx 11 \text{ } ка.^{(1)}$$

Key: (1). kA.

In conclusion let us pause at the determination of voltages at different points of network/grid during short circuits. During three-phase short circuit the voltage in the place of short circuit is equal to zero. Voltage at any point of network/grid, distant from the place of short circuit to resistor/resistance of x, is numerically equal to a voltage drop across this resistor/resistance with the course on it of the current of the three-phase short circuit:

$$U_к = \sqrt{3} I_к x. \qquad (6\text{-}50)$$

Utilizing a system of relative unity, it is possible to write:

$$U_{*\kappa} = I^{(3)}_{*\kappa} x_{*}$$

or

$$U_{\kappa}\% = I^{(3)}_{*\kappa} x_{*} 100 \qquad (6\text{-}51)$$

and further in the kilovolts:

$$U_{\kappa} = U_{*\kappa} U_{cp} = I^{(3)}_{*\kappa} x_{*} U_{cp}. \qquad (6\text{-}52)$$

In formulas (6.51) and (6-52) $I^{(3)}_{*\kappa}$ and x_{*} compulsorily they must be calculated under one and the same base line conditions.

Example of 6-5. Utilizing results of the calculation of example of 6-3 (Fig. 6-16), to determine voltage on the busbars of the primary side of substation during establishing mode/conditions of short circuit at point K-3.

In an example indicated is determined $I_{\infty K\text{-}3} = 5{,}6$ kA.

Ohmage from the point of short circuit to the busbars of the primary side of the substation (see Fig. 6.16b) composes

$$x = \frac{x_3}{3} + x_5 = \frac{0{,}28}{3} + 0{,}48 \approx 0{,}57 \overset{(1)}{\text{ом.}}$$

Key: (1). ohm.

The voltage drop across this section, in reference to the

step/stage of voltage $U_{cp\,2}=6{,}3$ kV, will compose

$$U_{\kappa(6,3)}=\sqrt{3}I_{\infty K\text{-}3}x=\sqrt{3}\cdot 5{,}6\cdot 0{,}57\approx 5{,}5\ \kappa в.^{(1)}$$

Key: (1). kV.

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Voltage on the busbars of the primary side of the substation

$$U_{\kappa(115)}=U_{\kappa(6,3)}\frac{U_{cp\,2}}{U_{cp\,1}}=5{,}5\ \frac{115}{6{,}3}\approx 100\ \kappa в.^{(1)}$$

Key: (1). kV.

or in percentages of $U_{cp\,2}=115$ kV

$$U_{\kappa}\%=\frac{U_{\kappa(115)}}{U_{cp\,2}}\,100=\frac{100}{115}\,100\approx 87\%.$$

Let us determine the same voltage, by utilizing a system of relative unity.

Relative value of short-circuit current, which flows into point K-3:

$$I_{*\infty K\text{-}3}=\frac{1}{x_{*рез\,K\text{-}3}}=\frac{1}{1{,}66}\approx 0{,}60.$$

or otherwise

$$I_{*\infty K\text{-}3}=\frac{I_{\infty K\text{-}3}}{I_{б}}=\frac{5{,}6}{9{,}2}\approx 0{,}60.$$

Relative base line resistor/resistance of section from K-3 to

the busbars of the substation

$$x_* = \frac{x_2}{2} + x_3 = \frac{0,7}{3} + 1,22 \approx 1,45.$$

Voltage on the busbars of substation according to formula (6.52):

$$U_{\kappa(115)} = I_{*\infty\, K\text{-}3} x_* U_{cp\,1} = 0,60 \cdot 1,45 \cdot 115 \approx 100 \overset{(1)}{\kappa s}.$$

Key: (1). kV.

or in percentages of $U_{cp\,2}$

$$U_\kappa\% = I_{*\infty\, K\text{-}3} x_* 100 = 0,60 \cdot 1,45 \cdot 100 \approx 87\%.$$

6.6. Short circuit in the circuit, which feeds from generators without automatic field regulators.

A change in the short-circuit current i_κ and by its periodic i_n and aperiodic i_a of the components during short circuit in the circuit, which feeds from generator without automatic field control, it is shown in Fig. 6-18. Short circuit is assumed at the moment/torque when emf of generator is equal to zero. As earlier, accept that the effective resistance of the short-circuited circuit is small in comparison with its inductive reactance.

As a result of the absence of automatic field regulator the current and the magnetic flux of excitation in the process of short circuit remain constant/invariable.

Without submerging in the part of the process of the sudden short circuit of alternator, examined/considered in course "electrical machines" [L. 6-2], let us recall the here only fundamental reasons, which cause a change in the time of component/term and, consequently, also full of short-circuit current.

In the relation to the reason for the onset, character of attenuation and conditions, which are determining the value of aperiodic of component/term, everything said in §6-5 completely remains valid and for the present case of short circuit.

A fundamental difference in the case of short circuit in question from short circuit with the feed of circuit from the source of the unlimited power consists in the inconstancy of amplitudes by periodic by component/term, gradually changing from greatest initial value I''_m to smallest steady value $\sqrt{2}I_\infty$. This amplitude reduction, and therefore, also the effective values of periodic of component/term of current is caused by decrease in the process of the short circuit of emf of the stator of generator as a result of a gradual increase in the back induction of the reaction of stator, i.e., the decrease of the resulting air-gap flux of generator.

The periodic current i_n, lagging on phase behind emf of generator to angle, close to 90°, creates the magnetic flux of stator $\Phi_{ст}$ (Fig. 6-19), directed contrarily toward the magnetic flux of excitation $\Phi_в$ of generator, i.e., the magnetic flux, which is the longitudinal flow of the reaction of stator. However, since excitation winding possesses inductance, then engaged with it magnetic flux $\Phi_в$ cannot instantly change. Consequently, at the first moment of short circuit the magnetic flux, engaged with excitation winding, must remain constant/invariable.

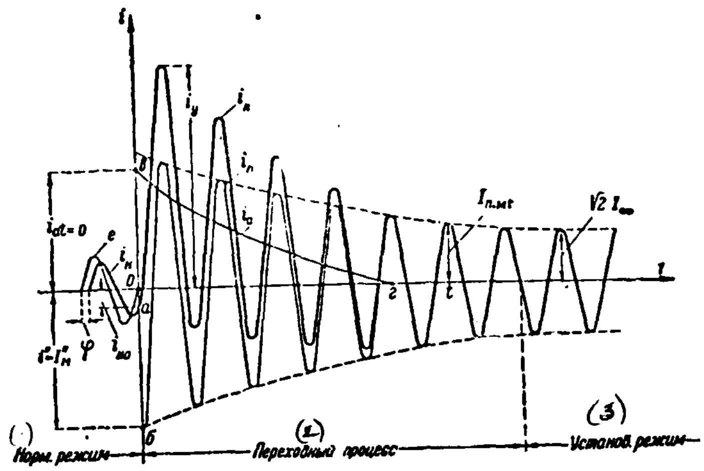

Fig. 6-18. Curve of a change of the short-circuit current in the circuit, which feeds from generator without automatic field regulator.

Key: (1). N. mode/conditions. (2). Transient process. (3). Adjust. mode/conditions.

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But this is possible only in such a case, whereas when in excitation winding at the first moment of short circuit appears supplementary, so-called free aperiodic current i_{cs}, having the same direction, as the field current I_s of generator, and supplementary free flow Φ_{cs}, created equal in magnitude and opposite in the direction to the

longitudinal magnetic flux of stator ($\Phi_{cв} = -\Phi_{cт}$). This free magnetic flux of rotor displaces the flow of stator on the way of scattering the rotor winding, as a result of which the magnetic flux, engaged with excitation winding, remains constant/invariable. Constant/invariable remains emf of generator.

Free currents are induced also in damping windings of rotor (in the presence their) and in its steel mass (flank of rotor), which also create some supplementary free magnetic fluxes, directed against the flow of stator. Therefore in actuality the longitudinal flow of stator is displaced on the way of scattering the rotor as a result of the combined action of the free magnetic fluxes, created with free coil currents of excitation, damper windings and steel mass of rotor.

Since excitation winding, damping windings and steel mass of rotor possess effective resistance, then induced in them at the first moment/torque free currents attenuate (on exponential curves) and is more rapid, the lower the time constant L/r of corresponding circuit ($i_{cв}$ in Fig. 6-20). With the attenuation of these free currents decrease the created by them free magnetic fluxes. As a result this flow of stator it gradually penetrates the outlines of rotor windings, the resulting air-gap flux of machine decreases, that also leads to the decrease of emf of stator and periodic component/term of the current of short circuiting. At the moment of the disappearance

of free circuital currents of excitation ceases a change in emf of generator and by periodic component/term of current - begins the steady mode/conditions of short circuit.

Thus, the duration of the transient process of short circuit is determined by the duration of a change in periodic in component/term of short-circuit current, which in turn, is determined by the time of delay of free currents in rotor windings. During short circuit on the terminals/grippers of generator the decay time by the periodic component/term, and thereby also transient period of short circuit is approximately/exemplarily 3-5 s.

In Fig. 6-20 it is shown that free current $i_{cв}$ into winding of the excitation of generator changes on an exponential curve from initial value $i_{cв\,t=0}$ to zero.

The aperiodic coil currents of the stator create motionless in space magnetic flux. During the rotation of rotor the excitation winding intersects the motionless flow of stator indicated; therefore in it is induced alternating current, which is superimposed on the free current of constant direction.

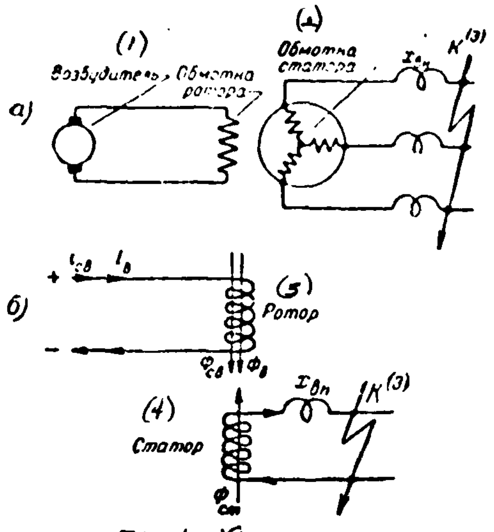

Fig. 6-19

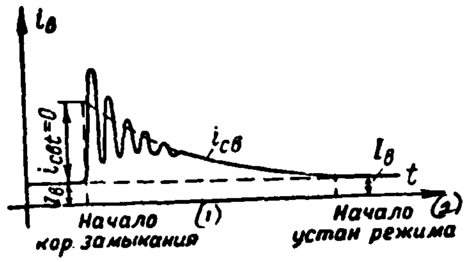

Fig. 6-20.

Fig. 6-19. Three-phase short circuit of generator.

Key: (1). Driver. Rotor winding. (2). Winding of stator. (3). Rotor. (4). Stator.

Fig. 6-20. Curve of change of coil current of excitation during short circuiting of generator without automatic field regulator.

Key: (1). Beginning of the crusts. of closing/shorting. (2). Began of establishment mode.

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As a result of this occurs the indicated in Fig. 6-20 pulsation of

coil current of excitation whose duration is determined by the time of delay of aperiodic armature currents (pain 0.2 s).

The instantaneous value of the periodic component/term for the arbitrary moment of time by us is marked i_n. The effective value of periodic of component/term I_{nt} for any moment/torque of time t conditionally take as the equal to its effective value during the period into the middle of which is located moment/torque t (accepting that for the duration of one period periodic component/term little differs from sinusoid). Corresponding to this moment/torque amplitude by periodic component/term $I_{n.mt}$ is found through curved, which envelopes amplitudes periodic component/term (dotted curves in Fig. 6-18). Thus, the effective value of the periodic of component/term for the arbitrary moment/torque of the time

$$I_{nt} = \frac{I_{n.mt}}{\sqrt{2}}.$$

During short circuit at moment/torque e=0 initial instantaneous value by periodic component/term i" will be maximum (I''_m). Disregarding the attenuation of the periodic components during the first period after the onset of short circuit, it is possible to consider that I''_m will be the amplitude of periodic of component/term during the period indicated.

The actual value of periodic of component/term during the first

period after the onset of short circuit, or as it usually call, initial ultratransitory short-circuit current,

$$I'' = \frac{I''_{\text{м}}}{\sqrt{2}}.$$

During three-phase short circuit this current can be calculated according to the formula:

$$I''^{(3)} = \frac{E''}{\sqrt{3}\,(x''_d + x_{\text{вн}})}, \qquad (6\text{-}53)$$

where E" - ultratransitory emf of the generator; x''_d - ultratransitory inductive reactance of generator (inductive reactance for an initial moment of short circuit); $x_{\text{вн}}$ - external inductive reactance of short circuit (from the terminals/grippers of generator to the place of short circuit).

Ultratransitory emf E" and ultratransitory inductive reactance x''_d are the parameters of generator, which characterize generator at the moment of disruption of its mode/conditions [6-2].

By index "(double prime) note the values, which relate to the ultratransitory mode/conditions of short circuit, i.e., to that initial period of short circuit when occur free currents in damper windings and steel mass of rotor. After the attenuation of these currents begins the transient mode/conditions of short circuit, which converts into that being steady after the attenuation of free coil

current of the excitation of generator.

Ultratransitory emf of generator E" can be approximately determined by the formula:

$$E'' \approx U_{\text{ном}} + \sqrt{3} I_{\text{ном}} x''_d \sin\varphi \approx kU_{\text{ср}}, \quad (6\text{-}54)$$

where $U_{\text{ном}} = U_{\text{ср}}$ - nominal voltage of the generator, taken equal to the medium voltage of the corresponding step/stage (see §6-3); $I_{\text{ном}}$ - the rated current of the generator; k - proportionality factor whose values are shown below.

In all cases of computing the short-circuit currents from turbogenerators, diverse generators and also hydraulic generators when $x_{\text{*расч}} > 1$ one should to accept k=1, i.e., count $E'' \approx U_{\text{ср}}$. During the computation of short-circuit currents from hydraulic generators when $x_{\text{*расч}} < 1$ the values of coefficient of k should be taken according to data of Table 6-1 [6-3].

Table 6-1. Values of coefficient of k for hydraulic generators.

(1) Тип гидрогенератора	(2) Значения коэффициента k при разных величинах расчетного сопротивления $x_{*\,расч}$						
	0,20	0,27	0,30	0,40	0,50	0,75	1,0
(3) Без успокоительной обмотки	—	1,16	1,14	1,10	1,07	1,05	1,03
(4) С успокоительной обмоткой	1,11	1,07	1,07	1,0	1,03	1,02	1,00

Key: (1). Type of hydraulic generator. (2). Values of coefficient of k with different values of calculated resistor/resistance. (3). Without damper winding. (4). With damper winding.

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If we substitute condition (6.54) into formula (6-53), then we will obtain the approximation formula for computing the initial ultratransitory current of three-phase short circuit, analogous to formula (6-27):

$$I''^{(3)} = \frac{kU_{cp}}{\sqrt{3}(x_d'' + x_{вн})} = \frac{kU_{cp}}{\sqrt{3}\,x_{рез}}. \quad (6\text{-}55)$$

After multiplying left and the right side of formula (6-55) on $\sqrt{3}U_{cp}$, we will obtain calculated expression for determining the ultratransitory power of the short circuit:

$$S'' = \sqrt{3}\,U_{cp}I'' = \frac{kU_{cp}^2}{x_{рез}}. \quad (6\text{-}56)$$

After expressing all values in relative unity under base line conditions and after fulfilling the same transformations as during the derivation of formulas (6-28) and (6-29), we will obtain:

$$I''^{(3)}_{*} = \frac{k}{x_{*рез}} \quad (6\text{-}57)$$

and

$$I''^{(3)} = \frac{k}{x_{*рез}} I_б. \quad (6\text{-}58)$$

Analogously is determined the ultratransitory power of the short circuit:

$$S'' = \frac{k}{x_{*рез}} S_б. \quad (6\text{-}59)$$

Impact current and effective value of full of short-circuit current during the first period determine by those brought out in §6-5 to formulas (6-34) and (6-38), replacing in them $I_к$ on I'':

$$i_y = k_y \sqrt{2} I''; \quad (6\text{-}60)$$

$$I_y = I'' \sqrt{1 + 2(k_y - 1)^2}. \quad (6\text{-}61)$$

During short circuit on the busbars, supplied directly from powerful/thick generators, should be accepted impact coefficient k_y= =1.9; then

$$i_y = 1{,}9 \sqrt{2} I'' = 2{,}7 I''. \quad (6\text{-}62a)$$

In all remaining cases of short circuits in installations by voltage it is higher than 1000 v, when is not considered the effective resistance of network elements, one should accept k_y =1.8

and

$$i_y = 1{,}8\sqrt{2}\,I'' = 2{,}55I''. \qquad (6\text{-}62б)$$

Impact coefficient upon consideration of effective resistance is determined in accordance with by indications §6-5.

Effective value of full of short-circuit current for the arbitrary moment of time taking into account the aperiodic component/term is determined from formula (6-37).

With an increase in the electrical distance of the place of damage the short-circuit current decreases and short circuit all to a lesser degree manifests itself the work of generators.

The distant point of short circuit conditionally is called such place in electrical circuit, during short circuit in which the current in the generators of station changes so insignificantly that it is possible to disregard a change in emf of generators and to consider voltage on their terminals/grippers constant/invariable and equal to normal (to medium nominal voltage of step/stage).

Therefore, during short circuit at the distant point they consider that periodic component/term of current does not change and with the first moment/torque of short circuit takes its steady value $I'' = I_{st} = I_{\infty}$. It is obvious that in this case the character of a change

of the circuital current will be the same as in the installation, which feeds from the source of the unlimited power (see Fig. 6-13).

Aperiodic component/term appears with any distance of the place of short circuit from generators, since the circuit possesses inductive reactance.

The virtually distant points of short circuit it is possible to consider all points for which $x_{*расч} > 3$.

Short-circuit current at the distant point can be determined by using the formulas, given in §6-5.

6-7. Short circuit in the circuit, which feeds from generators with automatic field regulators.

At present the generators of power plants, as a rule, supply with automatic field regulators. These regulators are intended for maintaining the assigned voltage of the generator by an automatic change in their field current with all divergences of variable voltage (for greater detail, see chapter 22). During short circuits load voltage of generator decreases and automatic regulator increases its field current.

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However, since automatic regulators possess certain proper time of action, then even with considerable a decrease in the voltage from the terminals/grippers of generator regulator comes in action with certain retardation, generally speaking in very small for contemporary automatic devices/equipment. Furthermore, and the considerable inductance of the excitation winding of generator leads to the delay of a change in the field current. As a result of entire this action of automatic field regulator in practice begins to manifest itself only after certain time after short circuiting. From the aforesaid it is possible to draw the conclusion that the automatic field regulators of generators do not affect the value of short-circuit current in the first periods of short circuit. The initial values of ultratransitory current and aperiodic of component/term and the process of its attenuation and, consequently, also impact current remain the same as with generators without automatic field regulators.

With a small electrical distance of short circuit from generators (at low value $x_{вн}$ in Fig. 6-19) the character of a change in the short-circuit current remains in fundamental the same as with generators without automatic field regulators (Fig. 6-18), but the value of periodic of component/term after certain time is obtained

considerably larger (curves 1 and 2 in Fig. 6-21). In this case load voltage of generator in the steady mode/conditions remains less than its nominal voltage even with a maximally possible increase in the excitation by automatic regulator, i.e.,

$$U_{\infty г} = \sqrt{3} I_{\infty} x_{вн} < U_{г.ном}.$$

With an increase in distance of short circuit the character of a change in periodic in component/term changes: first periodic component/term somewhat decreases, as earlier, as a result of the increase of the back induction of the reaction of stator, and then it begins gradually to increase, passing into the steady value of current (Fig. 6-22 and curve 3 in Fig. 6-21), which is explained by an increase in emf of generator as a result of the predominant effect of automatic field regulator. Large is obtained load voltage of generator in the steady mode/conditions.

With certain distance of short circuit it proves to be that the automatic field regulator restores load voltage of generator in the steady mode/conditions before nominal. Further increase $x_{вн}$ leads to the fact that load voltage of generator in the steady mode/conditions is restored to nominal with increasingly a smaller increase in the excitation of generator. In connection with this with the considerable distance of short circuit steady current I_{∞} can prove to be equal to the ultratransitory current I" (curve 4 in Fig. 6-21) or even exceed it (curve 5).

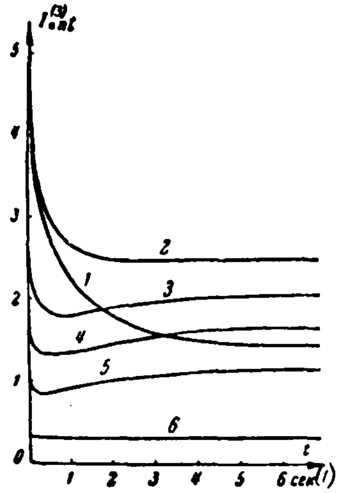

Fig 6-21

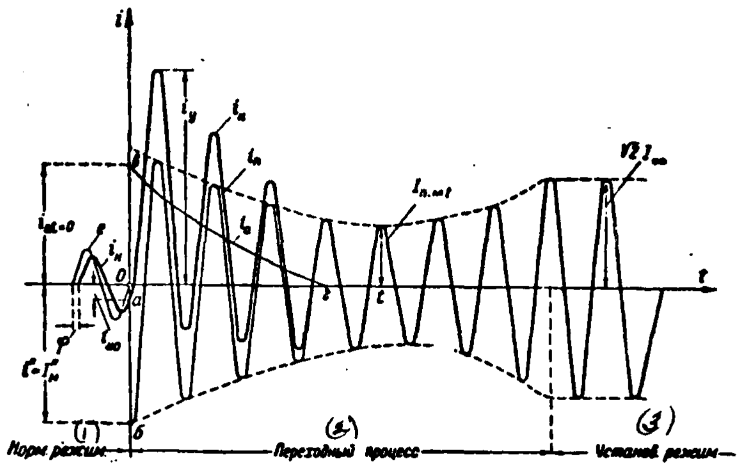

Fig. 6-22.

Fig. 6-21. Curves of change of the effective values of periodic of component/term of the current of short circuiting from turbogenerator. 1 - with turbogenerator without automatic field regulator and $x_{*расч}=0.2$; 2 - the same, but with automatic field regulator with $x_{*расч}=0.2$; 3 - the same, but with $x_{*расч}=0.4$; 4 - the same, but with $x_{*расч}=0.6$ $(I_{\infty}-I'')$; 5 - the same but with $x_{*расч}=1$ $(I_{\infty}>I'')$; 6 - when $x_{*расч}=3$ $(I''=I_{nt}-I_{\infty})$.

Key: (1). s.

Fig. 6-22. Curve of change of snort-circuit current in circuit, which feeds from generator with automatic field regulator.

Key: (1). N. mode/conditions. (2). Transient process. (3). Adjust.

mode/conditions.

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Let us note that condition $U_{ост} = U_{г.ном} = U_{ср}$ (or $U_{*ост} = 1$) occurs when $x_{*расч} \approx 1$.

During short circuit at distant point $(x_{*расч} \geqslant 3)$ it is considered (see §6-6) that load voltage of generator does not change, and consequently, automatic field regulator does not come in action and does not increase the field current of generator. This makes it possible to accept condition $I'' = I_{nt} = I_{\infty}$ (straight line 6 in Fig. 6-21).

6-8. Determination of short-circuit currents from calculated curves.

For determining the effective value of periodic of component/term I_{nt} at the moment of time t of the process of short circuit it is necessary to know emf of the generator for the same moment of time and inductive reactance of the short-circuited circuit, then:

$$I_{nt} = \frac{E_t}{\sqrt{3}\,(x_d'' + x_{вн})}, \quad (6\text{-}63)$$

where E_t - calculated emf of generator for the moment/torque of time

t of the process of short circuiting; x''_d - ultratransitory inductive reactance of the generator; $x_{вн}$ - external inductive reactance of short circuit.

Determination E_t is sufficiently complicated; therefore in practice designs the value of periodic of component/term of short-circuit current at different moments of time determine, using calculated curves (Fig. 6-23), making it possible to find the relative values of periodic of component/term of the current of three-phase short circuit at different moments of time depending on the calculated resistor/resistance of the circuit:

$$I^{(3)}_{*пt}=f(t;\ x_{*расч}).$$

Curves are constructed on the assumption that to short circuit the generators worked with full load with cos ϕ=0.8 and with nominal load voltage. Since the parameters of the generators of different types substantially are distinguished, then calculated curves are constructed according to the standard parameters of turbogenerators (Fig. 6-23 and 6-25) and hydraulic generators (Fig. 6-26) of domestic manufacture.

Are distinguished also calculated curves for generators without automatic field regulators (Fig. 6-23), also, with automatic field regulators (Fig. 6-25 and 6-26) [6-1].

As the basis of the calculations, connected with the construction of the calculated curves, is assumed the diagram in Fig. 6-24. To the terminals/grippers (collecting mains) of generator is connected the branch with fixed resistor $z_н$, imitating the nominal load of generator ($z_{*н}=0,8+j0,6$, i.e., $z_{*н}=1$ and $\cos\varphi_н=0,8$). Short circuit is taken after different external inductive reactances $x_{вн}$ of emergency branch, which to short circuit ran idle (Fig. 6-24a). Under the conditions accepted, as this was indicated earlier, short-circuit current in emergency branch will have great computed value.

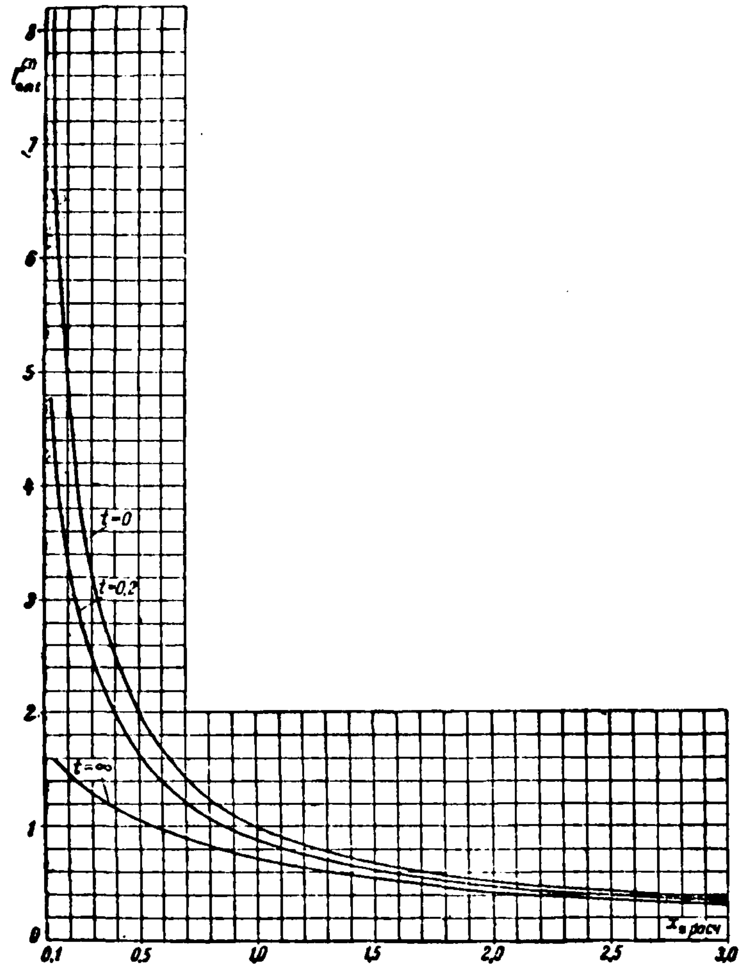

Fig. 6-23. calculated curves for determining periodic component/term of the current of three-phase short circuit in the place of damage with feed from standard turbogenerator without automatic field regulator.

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After accepting the average parameters of the generator and being assigned by different values $x_{вн}$, they calculated values E_t, and thereupon the value of periodic of component/term of the current of three-phase short circuit in emergency branch at different moments of time. In this case it was considered that the current in generator was equal to vector sum of currents in emergency branch in the branch of load (Fig. 6-24b). According to the obtained results were constructed calculated curves. Along the axis of abscissas on the graph/curve of these curves are deposited/postponed the relative values of the calculated resistor/resistance, equal to $x_{*расч}=x''_{*d}+x_{*вн}$, referred to the nominal power of generator $S_{г.ном}$, while along the axis of ordinates - relative values of the periodic of component/term in the emergency branch

$$I^{(3)}_{*nt}=\frac{I^{(3)}_{nt}}{I_{г.ном}},$$

where

$$I_{г.ном}=\frac{S_{г.ном}}{\sqrt{3}U_{ср}}.$$

Thus, calculated curves consider the previous load of the generator (conditionally referred to the terminals/grippers of generator), but into value $x_{*расч}$ the load resistance/resistor is not connected. This simplifies all calculations, since it makes it

possible completely to exclude from network and replacement scheme from which expect the short-circuit current, all loads and to consider only those network elements, on which flows/occurs/lasts the short-circuit current. It is at the same time necessary solidly to memorize, that with the use of calculated curves should be into the replacement scheme of network introduced the generators compulsorily by their inductive reactances x''_d for an initial moment of short circuit.

If the resulting resistor/resistance of short circuit $x_{рез}$ is calculated in ohms with certain base line voltage $U_б$, then with the use of calculated curves necessary to determine the relative calculated resistor/resistance of short circuit $x_{*\,расч}$, referred to the total nominal power of all generators $S_{ном\,\Sigma}$, from which is designed short-circuit current. For this translation can be used formula (6-9), represented in the following form:

$$x_{*\,расч} = \frac{S_{ном\,\Sigma}\, x_{рез}}{U_б^2}.$$

But if all resistors/resistances of short circuit were expressed in relative unity at certain arbitrarily selected base line power $S_б$, the obtained as a result of the transformation of replacement scheme value $x_{*\,рез}$ must be converted to the total nominal power of generators $S_{ном\,\Sigma}$ according to formula (6-23), which repeated here for convenience in further calculations:

$$x_{*\,расч} = x_{*\,рез} \frac{S_{ном\,\Sigma}}{S_б}.$$

Let us note that on calculated curves it is possible to determine only short-circuit current in the branch, directly connected with the place of short circuit. The use of calculated curves for determining the values of currents in the separate ones, distant from the place of short circuit, the branches of network/grid can lead to considerable errors. In this case are utilized other, more precise calculation methods which here are not set forth.

In the simplest case, similar to that given in Fig. 6-24, current in the branch of generator it is possible to determine as follows. For the specific moment of time by calculated curves is determined current I_{nt} in emergency branch, then they calculate voltage on the busbars of generator ($U=\sqrt{3}I_{nt}x_{вн}$ or $U_*=I_{*nt}x_{*вн}$), further according to the law. Ohm define current $I_{нt}$ in branch loads and finally current in the branch of generator, as vector sum is such I_{nt} and $I_{нt}$.

The mutual intersection of curves in Fig. 6-25 and 6-26 is explained by the effect of field regulators, about which it was said in §6-7.

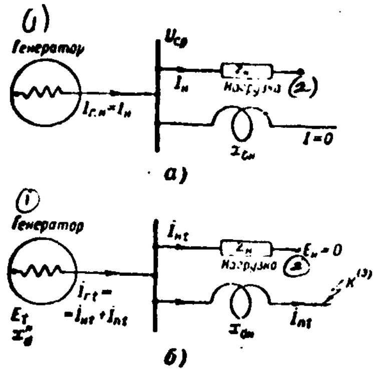

Fig. 6-24. Diagram, taken during the construction of calculated curves. a(normal (preceding) operating mode; b) three-phase short circuit at point $K^{(3)}$.

Key: (1). Generator. (2). Load.

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The use of calculated curves is very simple. After determining $x_{*расч}$ and knowing $S_{ном\Sigma}$ and $I_{ном\Sigma}=\frac{S_{ном\Sigma}}{\sqrt{3}U_{cp}}$ (with U_{cp} that step/stage, for which is designed the short-circuit current), they find through curve for the appropriate moment/torque of time $I^{(3)}_{*nt}$, and then

$$I^{(3)}_{nt}=I^{(3)}_{*nt}I_{ном\Sigma}. \qquad (6\text{-}64)$$

In particular, on curve for t=90 is determined $I''^{(3)}$, and then by formula (6-59) impact current i_y; but by curve for t=∞ they determine $I^{(3)}_\infty$.

The power of short circuit for the moment/torque of time t can be determined from the expression

$$S_{nt}^{(3)}=\sqrt{3}U_{cp}I_{nt}^{(3)}.$$

After dividing both parts of this equation on $S_{\text{ном}\Sigma}=\sqrt{3}U_{cp}I_{\text{ном}\Sigma}$, we find that $S_{*nt}^{(3)}=I_{*nt}^{(3)}$, i.e., the relative values of current and power of short circuit for certain moment of time are numerically equal. Therefore, after finding out by calculated curve $I_{*nt}^{(3)}$, it is possible the power of short circuit to determine by the formula:

$$S_{nt}^{(3)}=I_{*nt}^{(3)}S_{\text{ном}\Sigma}. \quad (6\text{-}65)$$

During the use of curves in Fig. 6-26 for hydraulic generators with damper windings it is necessary calculated resistor/resistance to increase by 0.07 (along the axis of abscissas to plot/deposit $x_{*\text{расч}}+0.07$); in this case for t<0.1 s should be used the dotted curves, and for t>0.1 s - solid.

Calculated curves are applied for calculating the short-circuit currents to $x_{*\text{расч}}=3$. During high resistors/resistances the point of short circuit is considered distant and short-circuit current is defined, as it is stated in §6-5.

It was previously indicated that aperiodic component/term of short-circuit current attenuates for the time, which does not exceed

0.2 s after the beginning of short circuit. Therefore calculated curves for time t>0.2 s virtually make it possible to determine the full/total/complete short-circuit current, which flows into the place of damage. If necessary full/total/complete short-circuit current for time t<0.2 s can be determined from formula (6-37), having preliminarily determined I_{nt} by the correspond of calculated curve and i_{at} according to formula (6-31).

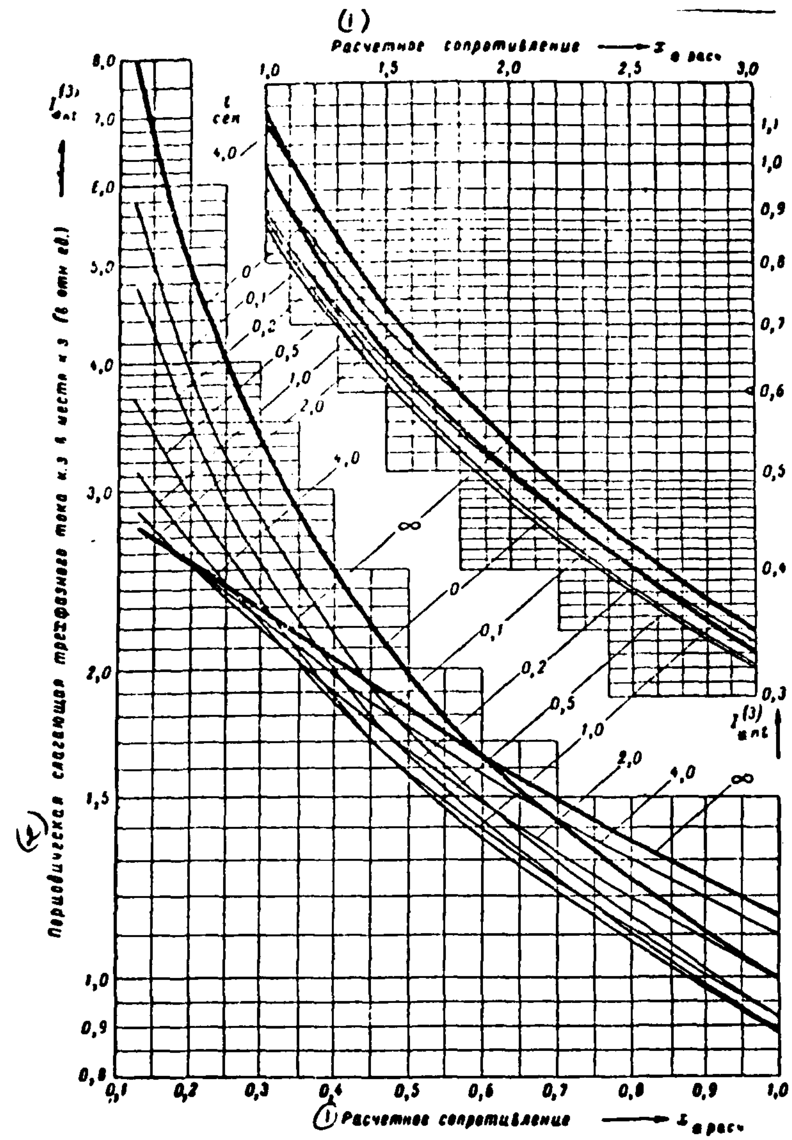

Fig 6-25. Calculated curves for determining periodic component/term of the current of three-phase short circuit in the place of damage with feed from standard of turbogenerator with automatic regulator of excitation.

Key: (1). Calculated resistor/resistance. (2). Periodic component/term of three-phase current short circuit into places short circuit (in rel. un.).

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For the selection of switches voltage it is higher than 1000 V according to the disconnecting ability (see Chapter 21) it is usually necessary to determine the full/total/complete value of short-circuit current for 0.1 s after the onset of short circuit [L. 3-6], i.e.,

$$I_{\kappa t=0,1} = \sqrt{I^2_{\pi t=0,1} + i^2_{a t=0,1}}.$$

Calculations they show that with sufficient accuracy it is possible to accept $I_{\kappa t=0,1} = I''$.

In conclusion let us point out that for the selection of electrical equipment of electrical stations, substations and networks/grids usually are determined the following values of short-circuit current: I" - for determining i_y, checking electrical equipment to thermal resistance and selection of the switches;

i_y - for checking electrical equipment to the electrodynamic

stability;

I_y - for the selection of some types of the automata (see Chapter 21);

I_∞ - for checking electrical equipment to thermal resistance.

When selecting of switches frequently is utilized the value of the ultratransitory power of short circuiting S".

The values of short-circuit current for other moments/torques time (I_{kt}) during design of power equipment do not usually determine.

Example 6-6. To determine I", S", i_y and I_∞ during three-phase short circuit at points K-1 and K-2 at the station whose diagram is given in Fig. 6-27. Necessary for calculation data are given in the diagram. At station are established/installed the turbogenerators, equipped with automatic field regulators.

Since are determined below only the currents of three-phase short circuit, then index (3) for simplification in the recordings is everywhere omitted.

In this case for basic power to it is more convenient accept

$$S_б = S_{ном\,\Sigma} = 3 \cdot 15 = 45\ Мва\ и\ U_б = U_{ср} = 6{,}3\ кв.$$

Key: (1). kV.

Then

$$I_б = I_{ном\,\Sigma} = \frac{S_{ном\,\Sigma}}{\sqrt{3}U_{ср}} = \frac{45}{\sqrt{3}\cdot 6,3} \approx 4,1 \overset{(1)}{ка.}$$

Key: (1). kA.

We lead all resistors/resistances to base line power. Relative basic resistors/resistances of the generators

$$x_1 = x_2 = x_3 = x''_{*d} \frac{S_{ном\,\Sigma}}{S_{г.ном}} =$$
$$= 0,126 \frac{45}{15} = 0,38.$$

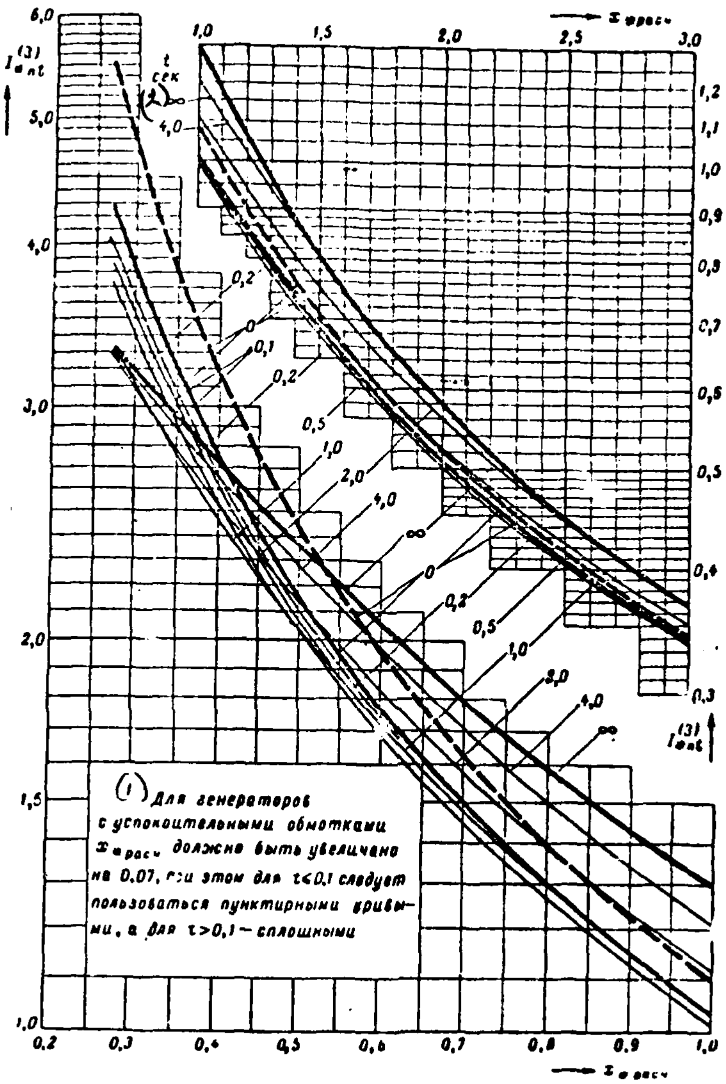

Fig. 6-26. Calculated curves for determining periodic component/term of the current of three-phase short circuit in the place of damage with feed from the standard hydraulic generator with automatic field regulator.

Key: (1). For generators with damping windings $x_{*расч}$ must be increased by 0.07; here for t<0.1 should be used the dotted curves, while for t>0.1 - solid. (2) s.

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Relative basic resistor/resistance of the reactor

$$x_{*} = x_{*p}\frac{I_{\text{ном}\,\Sigma}}{I_{p.\text{ном}}} = 0,05\frac{4,1}{0,2} \approx 1.$$

Replacement scheme is given in Fig. 6-27b. Short circuit at point K-1. Calculated resistor/resistance of circuit to point K-1

$$x_{*\text{расч}\,K\text{-}1} = \frac{x_{1}}{3} = \frac{0,38}{3} = 0,126.$$

We determine I", S" and i_y.

With t=0 on calculated curves (Fig. 6-25) we find $I''_{*} = 8$, then:

$$I'' = I''_{*} I_{\text{ном}\,\Sigma} = 8 \cdot 4,1 \approx 33 \ \overset{(1)}{\text{ка}};$$
$$S'' = I''_{*} S_{\text{ном}\,\Sigma} = 8 \cdot 45 = 360 \ \overset{(2)}{\text{Мва}};$$
$$i_y = 1,9\sqrt{2}I'' = 2,7I'' = 2,7 \cdot 33 = 89 \ \overset{(1)}{\text{ка}}.$$

Key: (1). kA. (2). MVA.

Initial ultratransitory current can be determined also by formula (6-58), accepting k=1:

$$I'' = \frac{k}{x_{*\text{расч}\,K\text{-}1}} I_{\text{ном}\,\Sigma} = \frac{4,1}{0,126} \approx 33 \ \overset{(1)}{\text{ка}}.$$

Key: (1). kA.

We determine I_∞.

With t=∞ through calculated curves we find $I_{*\infty}$ =2.75, then:

$$I_\infty = I_{*\infty} I_{\text{ном}\,\Sigma} = 2{,}75 \cdot 4{,}1 \approx 11{,}3 \text{ ка.}^{(1)}$$

Key: (1). kA.

Short circuit at point K-2.

Base line conditions remain the same.

$$x_{*\text{расч}\,K\text{-}2} = \frac{0{,}38}{3} + 1 \approx 1{,}1.$$

When $t=0$ $I''_* = 0{,}90$, then:

$$I'' = 0{,}90 \cdot 4{,}1 \approx 3{,}7 \text{ ка;}^{(1)}$$
$$S'' = 0{,}90 \cdot 45 \approx 40 \text{ Мва;}^{(2)}$$
$$i_y = 1{,}8\sqrt{2}\,I'' = 2{,}55 \cdot 3{,}7 \approx 9{,}4 \text{ ка.}^{(1)}$$

Key: (1). kA. (2). MVA.

When $t=\infty$ $I_{*\infty} = 1{,}02$, then:

$$I_\infty = 1{,}02 \cdot 4{,}1 \approx 4{,}2 \text{ ка.}^{(1)}$$

Key: (1). kA.

For a comparison let us conduct parallel calculation for point K-2, expressing all ohmages. network is given in Fig. 6-27c. Base line voltage $U_б = 6.3$ kV.

Resistors/resistances of the generators

$$x_1 = x_2 = x_3 = \frac{x''_{*d} U_б^2}{S_{г.ном}} = \frac{0,126 \cdot 6,3^2}{15} = 0,33 \text{ ом}^{(1)};$$

by Key: (1). ohm.

the resistor/resistance of the reactor

$$x_4 = \frac{x_р\%}{100} \frac{U_{р.ном}}{\sqrt{3} I_{р.ном}} =$$

$$= \frac{5}{100} \cdot \frac{6,3}{\sqrt{3} \cdot 0,2} = 0,91 \text{ ом}^{(1)}.$$

by Key: (1). ohm.

Resulting resistor/resistance of short circuit

$$x_{рез\, K\text{-}2} = \frac{0,33}{3} + 0,91 = 1 \text{ ом}^{(1)}.$$

Key: (1). ohm.

The relative calculated resistor/resistance

$$x_{*расч\, K\text{-}2} = \frac{S_{ном\, \Sigma} x_{рез\, K\text{-}2}}{U_б^2} =$$

$$= \frac{45 \cdot 1}{6,3^2} \approx 1,1,$$

i.e., the same value, as with the expression of resistors/resistances in relative unity. Consequently, and the values of short-circuit

current will be the same as determined above. Let us simply note that in this case the ultratransitory current can be also determined by formula (6-55) with k=1:

$$i'' = \frac{U_{cp}}{\sqrt{3}\,x_{pez\,K\text{-}2}} = \frac{6,3}{\sqrt{3}\cdot 1} \approx 3,6 \overset{(1)}{\kappa a.}$$

Key: (1). kA.

From the comparison of the values of the short-circuit currents, which flow into points K-1 and K-2, the evidently considerable effect of reactor on the amount of current and power of short circuit.

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At point K-2 $I_\infty > I''$, which is explained by the effect of the automatic field regulators of generators. In spite of this, the electrodynamic effect of current will be nevertheless more with impact current, since the latter is more than the amplitude of the steady current $(i_y > \sqrt{2} I_\infty)$.

Example 6-7. To determine I", S", i_y and I_∞ during three-phase short circuit at point K on the hydroelectric power plant whose diagram is given in Fig. 6-28. At station are established/installed the hydraulic generators with damping windings, the equipped with automatic field regulators. Triple-wound transformers have impedance voltages: $u_{\kappa\,B-C} =$ 17o/o; $u_{\kappa\,B-H} = 10{,}5\%$; $u_{\kappa\,C-H} = 6\%$. Remaining data are given in the diagram of station.

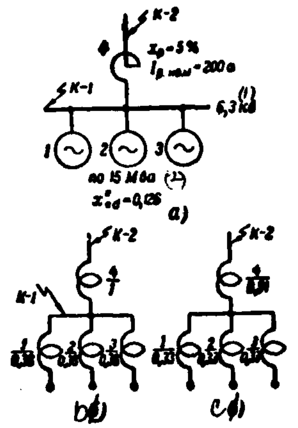

Fig. 6-27. Network and replacement scheme for example of 6-6.

Key: (1). kV. (2). MVA.

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Replacement scheme is given in Fig. 6-28b.

We accept base line power $S_б = 100$ MVA and we lead the relative resistors/resistances of diagram to base power.

Resistors/resistances of the generators

$$x_1 = x_2 = x_3 = 0{,}2\,\frac{100}{55} = 0{,}36.$$

Resistor/resistance of the double wound transformer

$$x_4 = 0{,}105\,\frac{100}{60} \approx 0{,}18.$$

According to formulas (6-14) we determine winding impedances of the triple-wound transformers:

$$x_{*B}=\frac{0,5}{100}(17+10,5-6)\approx 0,11;$$

$$x_{*C}=\frac{0,5}{100}(17+6-10,5)\approx 0,06;$$

$$x_{*H}=\frac{0,5}{100}(10,5+6-17)\approx 0.$$

Then

$$x_5=x_8=0;\ x_6=x_9=0,11\frac{100}{60}=0,18;$$

$$x_7=x_{10}=0,06\frac{100}{60}=0,1.$$

Voltage at points A and B is equal, which makes it possible to connect them. Then replacement scheme takes the form, given in Fig. 6-28c. Resistors/resistances x_1 and x_4 are connected in series, but x_6 and x_9, and also x_7 and x_{10} - in parallel. If we connect the neutrals of generators G-2 and G-3, then also resistors/resistances x_2 and x_3 they also prove to be connected in parallel. Then we obtain:

$$x_{11}=x_1+x_4=0,36+0,18=0,54;$$

$$x_{12}=\frac{x_6x_9}{x_6+x_9}=\frac{0,18}{2}=0,09;$$

$$x_{13}=\frac{x_2x_3}{x_2+x_3}=\frac{0,36}{2}=0,18;$$

$$x_{14}=\frac{x_7x_{10}}{x_7+x_{10}}=\frac{0,1}{2}=0,05.$$

After the connection of the neutrals of generators we determine the resulting resistor/resistance of the circuit:

$$x_{*\,рез}=\frac{(x_{11}+x_{12})\,x_{13}}{x_{11}+x_{12}+x_{13}}+x_{14}=$$

$$=\frac{(0,54+0,09)\,0,18}{0,54+0,09+0,18}+0,05=0,19.$$

We determine calculated resistor/resistance with $S_{ном\,\Sigma}=3\cdot 55=165$

MVA:

$$x_{*\,\text{расч}}=0,19\frac{165}{100}=0,31.$$

Since hydraulic generators have damper windings, then with the use of curves in Fig. 6-16 we plot/deposit along the axis of abscissas the resistor/resistance, equal to

$$x_{*\,\text{расч}}+0,07=0,31+0,07=0,38.$$

For determination I_*'' we use on the same reason for the broken line curve for t=0, on which we find $I_*''=3.45$. then:

$$I''=I_*''I_{\text{ном}\,\Sigma}=3,45\cdot 2,6\approx 9 \overset{(1)}{\text{ка}}.$$

Key: (1). kA.

where

$$I_{\text{ном}\,\Sigma}=\frac{165}{\sqrt{3}\cdot 37}=2,6 \overset{(1)}{\text{ка}};$$
$$i_y=1,8\sqrt{2}I''=2,55\cdot 9\approx 23 \overset{(1)}{\text{ка}};$$
$$S''=I_*''S_{\text{ном}\,\Sigma}=3,45\cdot 165\approx 570 \overset{(2)}{\text{Мва}}.$$

Key: (1). kA. (2). MVA.

Initial ultratransitory current can be determined also by formula (6-58). On Table 6-1 when $x_{*\,\text{расч}}=0,31$ we find k=-1.07. Then:

$$I''=\frac{k}{x_{*\,\text{расч}}}I_{\text{ном}\,\Sigma}=\frac{1,07}{0,31}2,6=3,45\cdot 2,6\approx 9 \overset{(1)}{\text{ка}}.$$

Key: (1). kA.

i.e., the same value, as found from calculated curves.

With $t=\infty$ $I_{*\infty}=2{,}83$ and $I_{\infty}=I_{*\infty}I_{\text{ном}\,\Sigma}=2{,}83\times$ 2.6=7.4 kA.

6-9. Calculation of short-circuit currents taking into account different distance of power supplies from the place of short circuit.

Above was examined the calculation of short-circuit currents according to the total calculated resistor/resistance of circuit, i.e., without the account to different distance of power supplies from the place of short, and consequently, on the assumption that generated by them periodic component/term of current change equally.

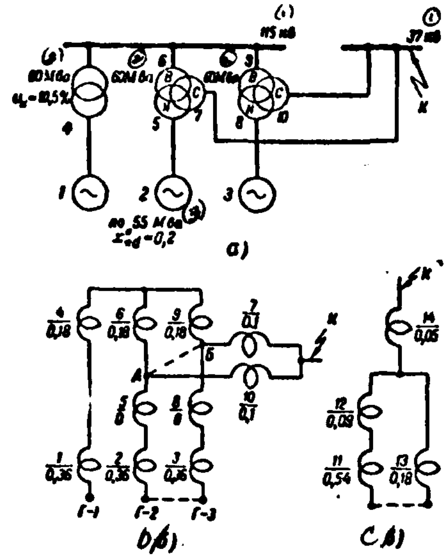

Fig. 6-18. Network and equivalent circuit for example 6-7.

Key: (1). kV. (2). MVA.

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However, in some diagrams power supplies can have such different distances from the place of damage, that the calculation of short-circuit currents for the intermediate moments of time, and especially for the steady mode/conditions of short circuit according to general/common/total calculated resistor/resistance can lead to very significant errors, since with different distance of sources generated by them periodic component/term change differently (see Fig. 6-21).

The varied conditions of changing periodic component/term of short-circuit current occur, also, with the feed of the place of short circuit from stations with turbogenerators and hydraulic generators. Is feasible the case of the feed of the place of short circuit simultaneously from station for final power and the system of the unlimited power.

The simplest case of the feed of the place of short circuit from two sources, having different distance, is given in Fig. 6-29a. Here each source is directly connected with the place of short; therefore the current of three-phase short circuit can be determined separately from each source. The current, which flows into the place of short circuit, is equal to the sum of short-circuit currents from sources. In this case one should remember that during the computation of short-circuit currents on calculated curves it is separate from sources necessary preliminarily for each of them to determine relative calculated resistor/resistance at the total nominal power of the generators of the corresponding source. So, if the resistors/resistances of the rays/beams of diagram x_1 and x_2 (Fig. 6-29a) are determined in ohms with certain $U_б$, then the calculated resistors/resistances of these rays/beams:

$$x_{*\,\text{расч}1} = \frac{S_{\text{ном}\,\Sigma 1} x_1}{U_б^2}$$

and

$$x_{*\,\text{расч}\,2}=\frac{S_{\text{ном}\,\Sigma 2}x_2}{U_6^2} \qquad (6\text{-}66,a)$$

But if x_1 about x_2 are determined in relative unity with certain S_6, then the calculated resistors/resistances of the rays/beams:

$$x_{*\,\text{расч}\,1}=x_1\frac{S_{\text{ном}\,\Sigma 1}}{S_6}$$

and

$$x_{*\,\text{расч}2}=x_2\frac{S_{\text{ном}\,\Sigma 2}}{S_6}. \qquad (6\text{-}66,б)$$

Somewhat more complicated than the case shown in Fig. 6-29b, where the short-circuit currents from both sources flow/occur/last through total resistance of x_3, in consequence of which news the calculation of currents directly from each source individually is already cannot. However, if we by converting this diagram lead it to diagram to radiation, similar diagram in Fig. 6-29a, then this already will make it possible to conduct the calculation of short-circuit currents from each source individually, taking into account different change of periodic of component/term of current. The conversion of the actual diagram indicated into radiation is possible with the observance of the following conditions: 1) short-circuit currents, which flow into the point of short and

generated by separate sources, they must remain constant/invariable and 2) the total resistance of radiation diagram must be equal to the total resistance of actual circuit. Order of calculation is the following:

1. Connect substitutions for the given point of short circuit and by gradual conversion they reduce it to the form, shown in Fig. 6-29b, where resistors/resistances x_1, x_2 and x_3 of three rays/beams can be expressed either in ohms with certain base line voltage $U_б$, or in relative unity at certain base line power $S_б$.

2. Is determined resulting resistor/resistance of diagram:

$$x_{рез} = \frac{x_1 x_2}{x_1 + x_2} + x_3.$$

3. They take the relative value of the periodic component/term of current in the place of short circuiting for unity ($I''_{*K} = 1$) and find distribution coefficients, i.e., fraction/portion participation in the short-circuit current of each of the sources.

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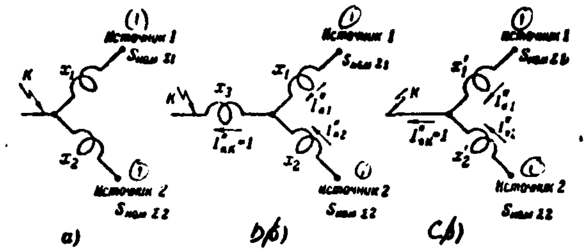

Fig. 6-29. Diagrams to the calculation of short-circuit currents taking into account different distance of sources from the place of short circuit.

Key: (1). Source.

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On the basis of Kirchhoff's law it is possible to write:

$$I''_{*1}+I''_{*2}=I''_{*K}=1 \text{ и } \frac{I''_{*1}}{I''_{*2}}=\frac{x_2}{x_1}.$$

Solving together these two equations, find distribution coefficients C for each source:

$$\left.\begin{aligned} C_1=I''_{*1}=\frac{x_2}{x_1+x_2}; \\ C_2=I''_{*2}=\frac{x_1}{x_1+x_2}, \end{aligned}\right\} \qquad (6\text{-}67)$$

or otherwise:

$$\left.\begin{aligned} C_1=\frac{x_9}{x_1}; \\ C_2=\frac{x_9}{x_2}, \end{aligned}\right\} \qquad (6\text{-}68)$$

where $x_0 = \frac{x_1 x_2}{x_1 + x_2}$ - general/common/total (equivalent) resistor/resistance of rays/beams from separate sources (rays/beams 1 and 2 diagrams in Fig. 6-29b). Formulas (6-68) are convenient for determining the distribution coefficients several power supplies.

The correctness of computations is checked according to the condition:

$$C_1 + C_2 = 1.$$

4. Is converted actual circuit (Fig. 6-29b) into radiation (Fig. 6-29c) with observance of conditions presented above which are expressed by following equations:

$$\frac{x_1' x_2'}{x_1' + x_2'} = x_{\text{рез}}$$

and

$$\frac{x_1'}{x_2'} = \frac{I_{*2}''}{I_{*1}''} = \frac{C_2}{C_1},$$

where x_1' and x_2' - conditional resistors/resistances, which connect sources directly with place of short circuit.

Values $x_{\text{рез}}$, C_1 and C_2 are known, therefore, solving together latter/last two equations, we find:

$$x_1' = \frac{x_{\text{рез}}}{C_1} \overset{(1)}{\text{и}} x_2' = \frac{x_{\text{рез}}}{C_2}. \qquad (6\text{-}69)$$

Key: (1). and.

The resistors/resistances of rays/beams x_1' and x_2' can be determined by replacing the diagram of star by the diagram of equivalent triangle (Fig. 6-11). Utilizing formulas (6-25), it is possible to write:

$$\left.\begin{aligned} x_1' &= x_1 + x_3 + \frac{x_1 x_3}{x_2}; \\ x_2' &= x_2 + x_3 + \frac{x_2 x_3}{x_1} \end{aligned}\right\} \quad (6\text{-}70)$$

(resistor/resistance x_3' of equivalent triangle which proves to be connected between sources 1 and 2, further they do not consider, since it does not affect the strength of current, which flows into the place of short circuit).

The use of formulas (6-70) is more convenient with isolation/liberation in the replacement scheme of two power supplies with different distance from the place of short circuit. With the isolation/liberation of a larger number of sources to more conveniently determine distribution coefficients according to formulas (6-68) and then resistors/resistances of rays/beams according to formulas (6-69).

By the obtained values of equivalent resistance x_1' and x_2' of radiation diagram (Fig. 6-29c) are determined relative calculated resistors/resistances $x_{*расч1}$ and $x_{*расч2}$ circuits from each source at the total nominal power of its generators. For this they use formulas (6-66a) or (6-66b) depending on that, are determined x_1' and x_2' in

ohms or relative unity.

Further is determined short-circuit current from each source individually. The sum of these currents gives the value of the current, which flows into the place of damage.

To resort to the calculation of current of short circuiting taking into account different change in periodic in component/term as considerably complicating computational work, follows only if this gives the essential refinement of the value of short-circuit current. It is obvious that great refinement of calculation this method gives during the computation of the steady short-circuit current of the flowing into place damage. Use of this method of the calculation of short-circuit current for the short times t gives refinement, as a rule, unessential for purposes of practice.

It is obvious that it does not make sense to apply this method of calculation during the determination of the initial values of short-circuit current I'' and i_y. Exception/elimination can be only the case, when it is necessary during the determination of impact current i_y to consider the different attenuation of aperiodic of component/term (different values of impact coefficient k_y) from power supplies of (see the definition k_y for point K. In example 6-10.)

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One ought not to also apply the considered method of calculation during the determination of short-circuit current the reactors and on the side of the secondary voltage of the substations of small and average/mean power, but frequently even powerful/thick substations, since their resistor/resistance usually considerably exceeds the resistor/resistance of all other network elements of short circuit, which strongly smooths difference in distance from the place of the short circuit of power supplies.

It goes without saying, should be separated/liberated the sources, connected directly to the place of short circuit, and also the electrical systems of the unlimited power, since periodic component/term from the latter is constant/invariable. Is expedient isolation/liberation into the separate groups of thermal power plants and hydroelectric power plants. One type stations with a comparatively small difference in distance from the place of short circuit it is expedient to unite into one group.

Example 6-8. To determine I'', I_t and I_∞ during three-phase short circuit at three points, indicated in the diagram of Fig. 6-30a, where are given all necessary for calculation data. In system and on district power plant are established/installed the turbogenerators

with automatic field regulators.

Full/total/complete replacement scheme for all calculation points is given in Fig. 6-30b.

Resistors/resistances let us express in relative units.

We accept $S_6 = 100$ MVA; we lead to it all relative resistors/resistances, as this repeatedly was done in the previous examples, and we inscribe them in the diagram of substitution.

Short circuit at point K-1.

Resulting resistor/resistance of circuit from the system

$$x_{*\,\text{рез.с}} = x_{16} = x_1 + \frac{x_6}{2} + \frac{x_{10}}{2} = 0,067 + \frac{0,117}{2} + \frac{0,181}{2} \approx 0,22.$$

Resulting resistor/resistance of circuit from local exchange

$$x_{*\,\text{рез.ст}} = x_{17} = \frac{x_9 + x_6}{2} + \frac{x_{13}}{2} = \frac{0,22 + 0,175}{2} + \frac{0,121}{2} \approx 0,26.$$

For both branches it is possible to accept $k_y = 1,8$, therefore the initial values of short-circuit current we determine by the total resistance:

$$x_{*\,\text{рез}\,K\text{-}1} = \frac{x_{16} x_{17}}{x_{16} + x_{17}} = \frac{0,22 \cdot 0,26}{0,22 + 0,26} \approx 0,12.$$

Medium voltage of the step/stage of short circuit $U_{cp} = U_б = 115$ kV; therefore

$$I_б = \frac{100}{\sqrt{3} \cdot 115} \approx 0.5 \overset{(1)}{\text{ка.}}$$

Key: (1). kA.

Ultratransitory current is determined from formula (6-58), after accepting k=1:

$$I''_{K\text{-}I} = \frac{I_б}{x_{*рез\, K\text{-}I}} = \frac{0,5}{0,12} \approx 4,2 \overset{(1)}{\text{ка.}}$$

Key: (1). kA.

Impact short-circuit current

$$i_{y\, K\text{-}I} = 1,8 \sqrt{2}\, I''_{K\text{-}I} = 2,55 \cdot 4,2 \approx 11 \overset{(1)}{\text{ка.}}$$

Key: (1). kA.

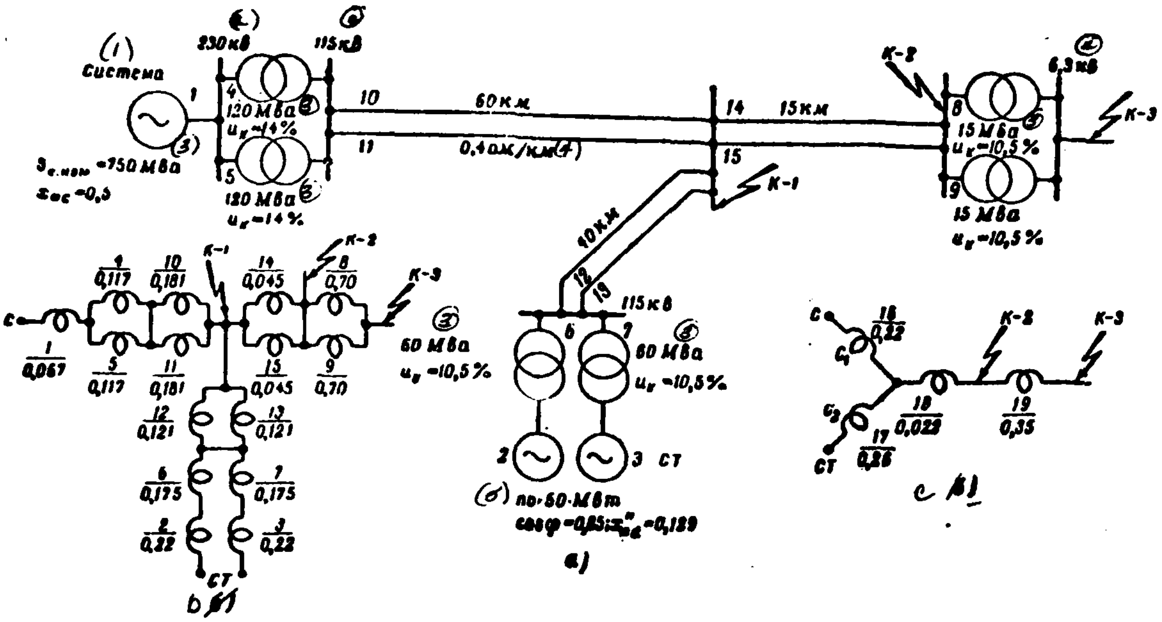

Fig. 6-30. Network and replacement scheme for example of 6-8.

Key: (1). System. (2). kV. (3). MVA. (4). Ω/km. (5). 50 MW each.

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The steady short-circuit current, which flows into point K-1, we determine separately from system and station.

Calculated resistor/resistance of system with $S_{c.ном}$ = 750 MVA:

$$x_{*\,расч.c}=0,22\frac{750}{100}\approx 1,6.$$

On curves in Fig. 6-25 with t=∞ we find

$$I_{*\,\infty}=0,68.$$

Since

$$I_{c.ном}=\frac{750}{\sqrt{3}\cdot 115}\approx 3{,}8\ \text{ка}^{(1)},$$

that

$$I_{\infty\,c}=0{,}68\cdot 3{,}8\approx 2{,}6\ \text{ка}^{(1)}.$$

Key: (1). kA.

Calculated resistor/resistance of station with $S_{ст.ном}=$ 250/0.85=117.6 MVA:

$$x_{*\,расч.ст}=0{,}26\,\frac{117{,}6}{100}\approx 0{,}3.$$

On calculated curves $I_{*\infty}=2{,}3.$ Since

$$I_{ст.ном}=\frac{117{,}6}{\sqrt{3}\cdot 115}=0{,}6\ \text{ка}^{(1)},$$

that

$$I_{\infty\,ст}=2{,}3\cdot 0{,}6\approx 1{,}4\ \text{ка}^{(1)}.$$

Key: (1). kA.

Total value of the steady short-circuit current:

$$I_{\infty\,K\text{-}1}=I_{\infty\,c}+I_{\infty\,ст}=2{,}6+1{,}4=4\ \text{ка}^{(1)}.$$

For a comparison let us determine the steady current by general/common/total calculated resistor/resistance.

The total power of all generators

$$S_{ном\,\Sigma}=750+117{,}6=867{,}6\ \text{Мва}^{(1)}.$$

Key: (1). MVA.

$$x_{*расч\,K\text{-}1} = 0,12\frac{867,6}{100} \approx 1.$$

calculated resistor/resistance

On decay curves $I_{*\infty} = 1,15$, then:

$$I_{\infty\,K\text{-}1} = 1,15 \cdot 4,4 = 5 \text{ ка}^{(1)}$$

where

$$I_{ном\,\Sigma} = \frac{867,6}{\sqrt{3} \cdot 115} \approx 4,4 \text{ ка}^{(1)}.$$

Key: (1). kA.

The error for calculation according to total resistance comprises $\frac{5-4}{4}100 = 25\%$. i.e., it is very significant.

Short circuit at point K-2.

Utilizing results of the preceding/previous calculation, we compose for point K-2 the simplified replacement scheme, given in Fig. 6-30c, where

$$x_{18} = \frac{x_{14}}{2} = \frac{0,045}{2} \approx 0,022.$$

Resulting resistor/resistance:

$$x_{*рез\,K\text{-}2} = x_{*рез\,K\text{-}1} + x_{18} = 0,12 + 0,022 \approx 0,14.$$

We determine the initial values of short-circuit current with

$U_{cp} = 115$ kV:

$$I''_{K-2} = \frac{0,5}{0,14} \approx 3,6 \text{ ka}^{(1)}$$

and

$$i_{y\,K-2} = 1,8\sqrt{2}\cdot 3,6 \approx 9,2 \text{ ka}^{(1)}.$$

Key: (1). kA.

The steady current is determined in a presented above manner, which considers different distance of power supplies from point K-2.

Distribution coefficients according to formulas (6-68):

$$C_1 = \frac{x_{*9}}{x_{10}} = \frac{0,12}{0,22} \approx 0,55;$$
$$C_2 = 1 - 0,55 = 0,45.$$

Calculated resistors/resistances of the rays/beams of system and station according to formulas (6-69) and (6-66b):

$$x_{*\text{расч.с}} = \frac{x_{*\text{ рез}} S_{\text{с.ном}}}{C_1 S_6} = \frac{0,14}{0,55} \cdot \frac{750}{100} = 1,9;$$
$$x_{*\text{ расч.ст}} = \frac{0,14}{0,45} \cdot \frac{117,6}{100} \approx 0,36.$$

Current from the system

$$I_{*\infty} = 0,56 \text{ и } I_{\infty\,\text{с}} = 0,56\cdot 3,8 \approx 2,1 \text{ ka}^{(1)}.$$

Key: (1). kA.

$$I_{*\infty} = 2,16 \text{ и } I_{\infty\,\text{ст}} = 2,16\cdot 0,6 = 1,3 \text{ ka}^{(1)}.$$

Current from Key

$$I_{\infty\,K-2} = 2,1 + 1,3 = 3,4 \text{ ka}^{(1)}.$$

station: (1). kA.

Total value of the steady short-circuit current:

Key: (1). kA.

For a comparison let us determine the steady current by the general/common/total calculated resistor/resistance:

$$x_{*\text{расч}\,K\text{-}2} = 0,14\frac{867,6}{100} \approx 1,21;$$

$$I_{*\infty} = 0,92 \text{ и } I_{\infty\,K\text{-}2} = 0,92\cdot 4,4 \approx 4 \overset{(1)}{\text{ка}}.$$

Key: (1). kA.

Error

$$\frac{4-3,4}{3,4}100 = 18,2\%.$$

Short circuit at point K-3.

Replacement scheme is given in Fig. 6-29c, where

$$x_{10} = \frac{x_8}{2} = \frac{0,70}{2} = 0,35;$$

then

$$x_{*\text{рез}\,K\text{-}3} = x_{*\text{рез}\,K\text{-}2} + x_{10} = 0,14 + 0,35 \approx 0,49$$

Initial values of short-circuit current with $U_{\text{ср}} = 6,3$ kV and $I_6 = \frac{100}{\sqrt{3}\cdot 6,3} = 9,2$ kA:

$$I''_{K\text{-}3} = \frac{9,2}{0,49} \approx 18,7 \overset{(1)}{\text{ка}}$$

and

$$i_{y\,K\text{-}3} = 1,8\sqrt{2}\cdot 18,7 \approx 48 \overset{(1)}{\text{ка}}.$$

Key: (1). kA.

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The steady current is determined taking into account different attenuation of periodic cf component/term from power supplies.

Distribution coefficients remain the same as in the case of short circuit at point K-2, then

$$x_{*расч.с}=\frac{0,49}{0,55}\cdot\frac{750}{100}=6,7;$$

$$x_{*расч.ст}=\frac{0,49}{0,45}\cdot\frac{117,6}{100}\approx 1,3.$$

Periodic component/term of short-circuit current from system does not change $(x_{*расч.с}>3)$, therefore

$$I_{\infty с}=\frac{I_{с.ном}}{x_{*расч.с}}=\frac{69}{6,7}\approx 10,3\ ка.\ kA,$$

where

$$I_{с.ном}=\frac{750}{\sqrt{3}\cdot 6,3}\approx 69\ ка.\ kA.$$

Current from the station:

$$I_{*\infty}=0,84;$$

$$I_{ст.ном}=\frac{117,6}{\sqrt{3}\cdot 6,3}\approx 11\ ка;\ kA;$$

$$I_{\infty\ ст}=0,84\cdot 11\approx 9,3\ ка.\ kA.$$

Total value of the steady current;

$$I_{\infty\ K\text{-}3}=10,3+9,3=19,6\ ка.\ kA.$$

Calculation according to the general/common/total calculated

resistor/resistance

$$x_{*расч\ K-3} = 0{,}49\frac{867{,}6}{100} = 4{,}25.$$

The point of short circuit is distant $(I'' = I_{nt} = I_{\infty})$. therefore

$$I_{\infty\ K-3} = I''_{K-3} = 18{,}7\ ка.$$ kA.

The error for calculation according to total resistance composes in all (19.6-18.7/19.6)100=4.6o/o, i.e., in this case one ought not to have complicated calculation by the account of different change in periodic in component/term of short-circuit current from sources.

6-10. Calculation of short-circuit currents taking into account electrical system.

For the calculation of short-circuit currents on the power plants, which work in parallel with electrical systems, and also on substations it is necessary to have available the data, which characterize system.

If are known schematic of system and all necessary for the calculation of short-circuit currents parameters of generators, transformers and transmission lines then short-circuit current from system is designed, as it is stated earlier.

Is considerably simpler the calculation of short-circuit currents when are known the total nominal power of generators systems

$S_{c\,ном}$ and the total resistance of all elements of its network x_c to certain point of the network of the system to which is connected the projected/designed station or substation. The resistor/resistance of system can be expressed in ohms with certain base line voltage $U_б$ or in relative unity. The latter is normally assigned by that referred to the nominal power of system. In these all cases the short-circuit currents design from rules presented earlier, accepting system as certain equivalent generator of assigned total power $S_{c\,ном}$, possessing assigned total resistance x_c (see above example 6-8).

Can be also assigned the nominal power of system and the ultratransitory power of short circuit from system during short circuit at the fixed point of network. In this case it is not difficult to determine the resistor/resistance of system to the given point of short circuit.

The resistor/resistance of system in ohms can be determined by formula (6-56), after assuming in it k=1:

$$x_c = \frac{U_{cp}^2}{S''}, \qquad (6\text{-}71)$$

where U_{cp} - medium voltage of that step/stage where is accepted the point of short circuit, for which is assigned the power of short circuit from system S''.

The resistor/resistance of system in relative unity, in

reference to its nominal power (calculated resistor/resistance of system), can be determined by formula (6-59), after assuming in it $S_б = S_{c.ном}$ and k=1:

$$x_{*c} = \frac{S_{c.ном}}{S''}. \quad (6\text{-}72)$$

Calculation they further conduct as usually.

In very powerful/thick system, especially if it can considerably be developed, frequently with the calculation of short-circuit currents at stations and substations it is possible to accept that the power of system unlimitedly large ($S_{c.ном} = \infty$ and $x_c = 0$), and to consider only the resistor/resistance of those elements/cells of network (transmission lines of the transformer), through which the station or substation is connected to system.

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Finally, is feasible the case, when system is characterized only by the that type of the switch which can be established/installed on that installation of the system to which they connect this station or substation. Let us examine for an example diagram in Fig. 6-31. The parameters of all elements/cells of station and its connection/communication with the busbars of district substation are known. Is assigned the type of the switch V, which can be established/installed on the waste/exiting line of district

substation. On reference data or catalog to the switches (see Table P-14) find power cutoffs/disconnections $S_{отк}$ of assigned type switch (with the assigned voltage; for greater detail, see chapter 17).

It is obvious that the switch V can be established/installed on substation only in such a case, when the ultratransitory power of short circuit at point K-1 does not exceed the power of the cutoff/disconnection of switch, i.e., if is observed condition $S''_{K\text{-}1} \leqslant S_{отк}$.

After determining the power of short from station $S''_{ст.K\text{-}1}$ and after accepting $S''_{K\text{-}1} = S_{отк}$, is determined by the greatest possible power of short circuit from the system:

$$S''_{с.K\text{-}1} = S_{отк} - S''_{ст.K\text{-}1}.$$

Then is determined the resistor/resistance of system to point K-1 by formula (6-71) or (6-72) depending on whether are expressed ohmages or relative unity. In the case of calculation in question accept $S_{с.ном} = \infty$, therefore the relative resistor/resistance of system according to formula (6-72) is determined at certain base line power (substituting in this formula $S_б$ for $S_{с.ном}$).

Further, are designed short-circuit currents on the assumption that periodic component/term of current from system in time does not change.

In the case of connection to the system of substation the resistor/resistance of system by the known type of switch is determined analogously, equalizing the power of the cutoff/disconnection of the switch of the power of short circuit from system.

Example 6-9. To determine I'', S'' and I_∞ during three-phase short circuit at point K-2 in the diagram of Fig. 6-31a, where are given all necessary for calculation data. At station are established/installed the turbogenerators with automatic field regulators.

The power of the cutoff/disconnection of switch V with voltage 110 kV is

$$S_{отк} = 4000 \text{ MVA.}$$

Let us assume that periodic component/term of short-circuit current from system in time does not change, i.e., that point K-1 for the generators of system is distant.

We carry out calculation, expressing ohmages. For base line

voltage we accept the medium voltage of the step/stage of the short circuit

$$U_б = U_{ср} = 115 \text{ kV}.$$

We compute the resistors/resistances of all network elements in ohms with the base line voltage accepted and inscribe them in the diagram of the substitution:

$$x_1 = x_2 = x_3 = \frac{x''_{*d} U_б^2}{S_{г.ном}} = \frac{0{,}117 \cdot 115^2 \cdot 0{,}9}{100} = 14 \text{ ом};$$

$$x_4 = x_5 = x_6 = \frac{u_к\%}{100} \frac{U_б^2}{S_{т.ном}} = \frac{10{,}5}{100} \cdot \frac{115^2}{120} = 11{,}6 \text{ ом};$$

$$x_7 = x_8 = 40 \cdot 0{,}4 = 16 \text{ ом}.$$

Key: (1). ohm.

We determine the ultratransitory power of short circuit from station at point K-1:

$$x_{рез} = \frac{14 + 11{,}6}{3} + \frac{16}{2} = 16{,}5 \text{ ом};$$

$$S''_{ст.К-1} = \frac{115^2}{16{,}5} = 800 \text{ Мва}.$$

Key: (1). ohm. (2). MVA.

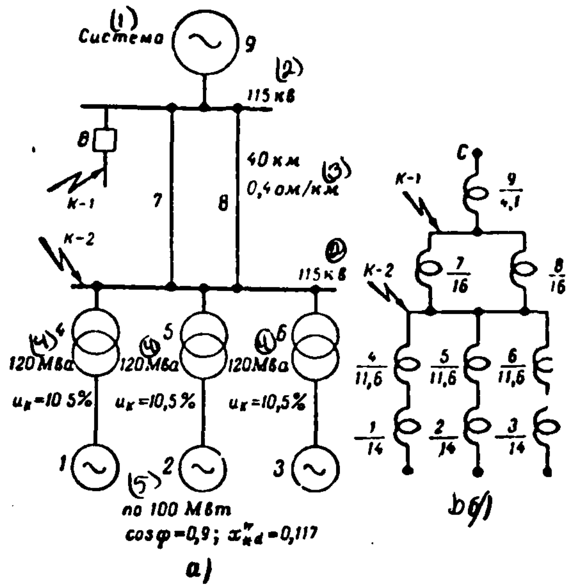

Fig. 6-31. network and replacement scheme for example of 6-9.

Key: (1). System. (2). kV. (3). Ω/km. (4). MVA. (5). on 100 MW.

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We determine the resistor/resistance of system.

Maximum possible power of short circuit from the system

$$S_{c\ K\text{-}1} = 4\,000 - 800 = 3\,200 \text{ MVA}$$

then according to formula (6-71)

$$x_c = x_s = \frac{U_б^2}{S_{c.K-1}} = \frac{115^2}{3\,200} = 4{,}1 \text{ ohm.}$$

Short circuit at point K-2.

We determine the resulting resistor/resistance of short circuit:

$$x_{рез.с} = 4{,}1 + \frac{16}{2} = 12{,}1 \overset{(1)}{\text{ом}};$$

$$x_{рез.ст} = \frac{14 + 11{,}6}{3} = 8{,}53 \overset{(1)}{\text{ом}};$$

$$x_{рез\,K-2} = \frac{12{,}1 \cdot 8{,}53}{12{,}1 + 8{,}53} \approx 5 \overset{(1)}{\text{ом}}.$$

Key: (1). ohm.

Then

$$I''_{K-2} = \frac{115}{\sqrt{3} \cdot 5} = 13{,}2 \quad \text{kA}$$

$$S''_{K-2} = \sqrt{3} \cdot 115 \cdot 13{,}2 = 2\,530 \quad \text{MVA.}$$

We will determine the steady short-circuit current, flowing into point K-2. According to condition accept that periodic component/term of short-circuit current from system in time does not change;

therefore

$$I_{\infty c} = I_c'' = \frac{115}{\sqrt{3} \cdot 12,1} \approx 5,5 \quad \text{kA}.$$

From the generators of station by that being steady the current at point K-2 must be determined by calculated curves in Fig. 6.25.

Calculated resistor/resistance from the generators of station to point K-2

$$x_{*расч.ст} = \frac{S_{ном\,\Sigma} x_{рез.ст}}{U_б^2} = \frac{333 \cdot 8,53}{115^2} = 0,21,$$

where

$$S_{ном\,\Sigma} = \frac{3 \cdot 100}{0,9} = 333 \quad \text{MVA}.$$

On calculated curve for t=∞ we find

$$I_{*\infty} = 2,55 \quad \text{kA}$$

then

$$I_{\infty\,ст} = 2,55 \cdot 1,7 \approx 4,3 \quad \text{kA}$$

where

$$I_{\infty\, \text{т}} = \frac{333}{\sqrt{3} \cdot 115} \approx 1{,}7 \text{ kA.}$$

Is final

$$I_{\infty\, K\text{-}2} = I_{\infty\, \text{c}} + I_{\infty\, \text{ст}} = 5{,}5 + 4{,}3 = 9{,}8 \text{ kA.}$$

Example 6-10. To determine I**, i_y and I_∞ during three-phase short circuit at point K in the diagram of Fig. 6.32a where are given all data, necessary for calculation. At both stations are established/installed the turbogenerators with automatic field regulators.

Replacement scheme is given in Fig. 6-32b. We will take $S_б = 100$ MVA, we bring to it entire relative resistances and we inscribe them on the equivalent circuit.

We convert the triangle of resistors/resistances x_{10}, x_{11} and x_{12} into the equivalent star of resistors/resistances x_{13}, x_{14} and x_{15}, utilizing formulas (6-24), and after simple conversions we obtain the simplified replacement scheme, given in Fig. 6.32c.

We determine the initial values of short-circuit current. Short circuit is assumed on the busbars of the generator voltage of power plant ST-2; therefore during determination i_y, we should accept for the branch of generators of station ST-2 $k_y = 1{,}9$, and

of system S and station ST-1 $k_y = 1{,}8$.

We accept

$$U_б = U_{ср} = 10{,}5 \quad \text{kV}$$

then

$$I_б = \frac{100}{\sqrt{3} \cdot 10{,}5} = 5{,}5 \quad \text{kA.}$$

From station ST-1 and system S:

$$x_{\text{рез}} = \frac{0{,}127 \cdot 0{,}097}{0{,}127 + 0{,}097} + 0{,}197 = 0{,}25;$$

$$I''_{\text{с.ст-1}} = \frac{5{,}5}{0{,}25} = 22 \ \text{kA.}$$

From the generators of station ST-2:

$$x_{\text{рез}} = x_{10} = \frac{0{,}422}{2} = 0{,}211;$$

$$I''_{\text{ст-2}} = \frac{5{,}5}{0{,}211} = 26 \ \text{kA.}$$

Total values of the initial currents, which flow into point K:

$$I'' = 22 + 26 = 48 \ kA;$$

$$i_y = 1{,}8 \sqrt{2} \cdot 22 + 1{,}9 \sqrt{2} \cdot 26 = 126 \ kA.$$

We determine the steady current from the generators of station ST-2:

$$S_{\text{ном}\,\Sigma}=2\frac{25}{0,8}=62,5\ \overset{(1)}{Мва};$$

$$I_{\text{ном}\,\Sigma}=\frac{62,5}{\sqrt{3}\cdot 10,5}=3,44\ \overset{(2)}{ка};$$

$$x_{*\text{расч.ст-2}}=0,211\frac{62,5}{100}=0,132.$$

Key: (1). MVA. (2). kA.

On calculated curves in Fig. 6-25 with t=∞ we find

$$I_{*\infty}=2,75,$$

then

$$I_{\infty\,\text{ст-2}}=2,75\cdot 3,44\approx 9,5\quad \text{kA}.$$

We determine by that being steady current from system S and ST-1 station taking into account different changes in periodic in component/term of short-circuit current.

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We pass to radiation diagram (Fig. 6-32d), after using formulas (6-70):

$$x_{*рез.с} = x_{16} + x_{18} + \frac{x_{16}x_{18}}{x_{17}} = 0,127 + +0,197 + \frac{0,127 \cdot 0,197}{0,097} = 0,68;$$

$$x_{*рез.\,ст\text{-}1} = x_{17} + x_{18} + \frac{x_{17}x_{18}}{x_{16}} = 0,097 + +0,197 + \frac{0,097 \cdot 0,197}{0,127} = 0,44.$$

The steady current from system S. Since the power of system is unlimitedly large, then periodic component/term of current from it does not change and can be determined according to formula (6-29):

$$I_{\infty\,c} = I''_c = \frac{I_б}{x_{*рез.с}} = \frac{5,5}{0,68} = 8,1 \text{ kA}.$$

Steady current from station ST-1:

$$S_{ном\,\Sigma} = 2\frac{100}{0,9} = 222 \text{ Мва}^{(1)};$$

$$I_{ном\,\Sigma} = \frac{222}{\sqrt{3} \cdot 10,5} = 12,2 \text{ ка}^{(2)};$$

$$x_{*расч.ст\text{-}1} = 0,44\frac{222}{100} = 0,98.$$

Key: (1). MVA. (2). kA.

On calculated curves with t=∞ we find

$$I_{*\infty} = 1,18,$$

then

$$I_{\infty\,ст\text{-}1} = 1,18 \cdot 12,2 = 14,4 \text{ kA}.$$

Total value of the steady current, which flows into point K,

$$I_{\infty}=9.5+8.1+14.4=32 \text{ kA}.$$

It is interesting to note that the steady short-circuit current, which flows into point K from system S and CT-1 ($I_{\infty\,c}+I_{\infty\,CT\text{-}1}=8.1+14.4=22.5$ kA) in practice does not differ from ultratransitory current from these sources ($I''_{c.CT\text{-}1}=22$ kA). Therefore, it is clear that in the cases, similar to that examined, one ought not to complicate calculations by the isolation/liberation of branches from the sources, considerably removed from the place of short circuit, as about this it was indicated in §6-9.

Example 6-11. To determine I'', i_y, S'' and I_{∞} during three-phase short circuit at points K-2 and K-3 in the diagram of Fig. 6-33, where are given all necessary data. System consists of a series/row of the hydroelectric power plants, on which are established/installed the hydraulic generators with damper windings, the equipped with automatic field regulators.

We accept

$$S_6=S_{c.\text{ном}}=500 \text{ MVA}$$

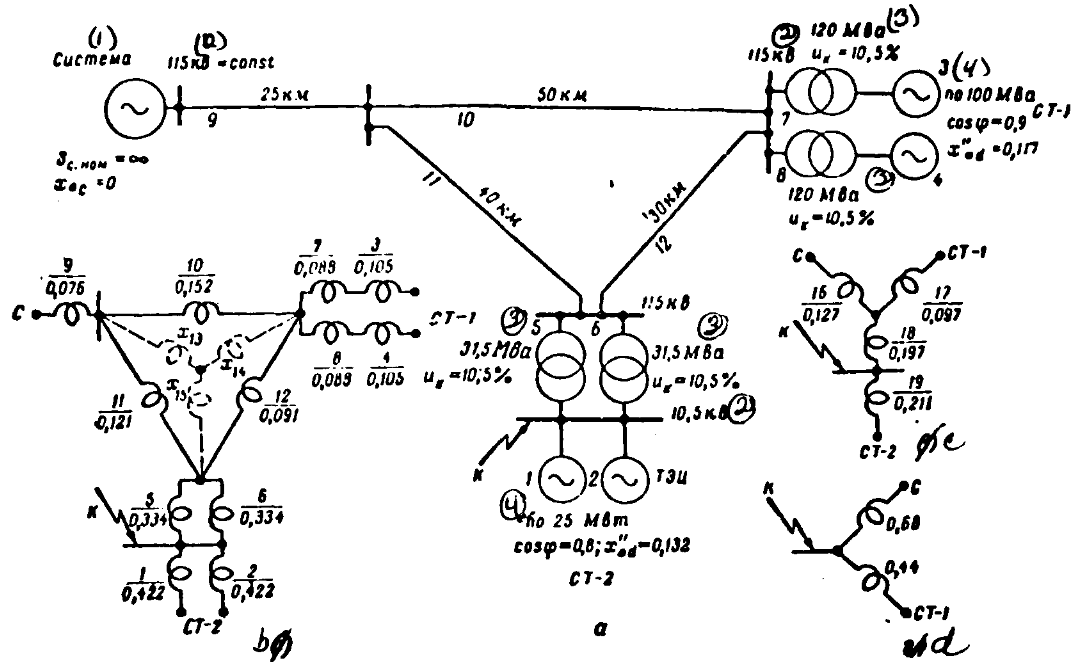

Fig. 6-32. Network and replacement scheme for example of 6-10.

Key: (1). System. (2). kV. (3). MVA. (4). on 100 MVA.

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The calculated resistor/resistance of system we determine from formula (6-72):

$$x_{*c} = x_{*расч\,K\text{-}I}\frac{S_{c.ном}}{S''_{K\text{-}I}} = \frac{500}{1\,000} = 0{,}5.$$

We connect of substitution and we lead all resistors/resistances

to base line power.

Short circuit at point K-2.

$$x_{*\text{расч} K\text{-}2} = 0,5 + \frac{1,46}{2} = 1,23.$$

On calculated curves on Fig. 6-26 we find the relative values of currents when $x_{*\text{расч} K\text{-}2} + 0,07 = 1,23 + 0,07 = 1,3$ (since hydraulic generators they are equipped with damper windings):

$I''_* = 0,83$ and $I_{*\infty} = 0,97$.

With $U_б = 37$ kV and

$$I_{\text{ном}\,\Sigma} = \frac{500}{\sqrt{3} \cdot 37} \approx 7,8 \text{ kA}$$

we find:

$$I'' = 0,83 \cdot 7,8 \approx 6,5 \ \text{ка};(1)$$
$$I_y = 1,8\sqrt{2} \cdot 6,5 \approx 17 \ \text{ка};(1)$$
$$S'' = 0,83 \cdot 500 = 415 \ \text{Мва};(2)$$
$$I_\infty = 0,97 \cdot 7,8 \approx 7,6 \ \text{ка}.(1)$$

Key: (1). kA. (2). MVA.

Short circuit at point K-3.

$$x_{*\text{расч.} K\text{-}3} = 1,23 + \frac{3,75}{2} \approx 3,1.$$

Since the point of short circuit distant, then with

$$U_б = U_{ср} = 6{,}3 \quad kV$$

and

$$I_{ном\,\Sigma} = \frac{500}{\sqrt{3}\cdot 6{,}3} = 45{,}7 \ ка;^{(1)}$$

$$I'' = I_\infty = \frac{45{,}7}{3{,}1} \approx 14{,}7 \ ка;^{(1)}$$

$$i_y = 1{,}8\sqrt{2}\cdot 14{,}7 \approx 38 \ ка;^{(1)}$$

$$S_к = \frac{500}{3{,}1} \approx 160 \ Мва.^{(2)}$$

Key: (1). kA. (2). MVA.

6-11. Determination of short-circuit current taking into account injection from asynchronous electric motors.

Let us examine the effect of asynchronous ele-tric motors on the value of the short-circuit current, using diagram in Fig. 6-34, where is shown electric motor D, connected to certain point A of electric system.

For an initial moment of short circuit generator and electric motor we introduce into diagram by their by ultratransitory of emf E'' and $E''_д$ and ultratransitory resistors/resistances x''_d and $x''_д$.

In the normal operation of emf of electric motor the somewhat less conducted/supplied to it voltage; therefore electric motor obtains feed from network. During short circuit the conducted/supplied to electric motor voltage is reduced and can prove to be above or below emf of engine.

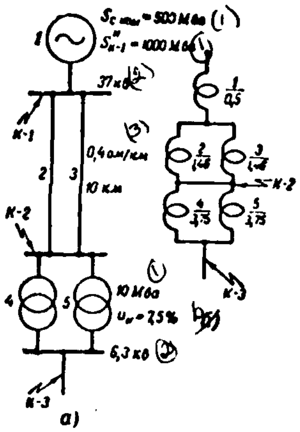

Fig. 6-33. Network and replacement scheme for example of 6-11.

Key: (1). MVA. (2). kV. (3). Ω/km.

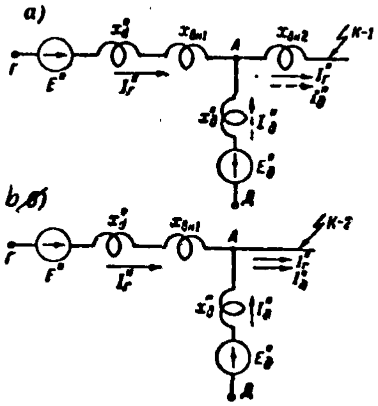

Fig. 6-34. Diagrams taking into consideration of injection of place of short circuit from asynchronous electric motors.

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If during short circuit, for example at point K-1 (Fig. 6-34a) it proves to be that $U_{д}>E''_{д}$, then electric motor will continue to work with the lowered/reduced rotational speed (since $U_{д}<U_{д\,ном}$), consuming current from network. But if it proves to be that $U_{д}<E''_{д}$, then electric motor will generate current into the place of damage K-1, as shown by broken rifleman/pointers $I''_{д}$ in Fig. 6-34a. In this case the electric motor rapidly brakes and the sent by it current into the place of damage greatly rapidly decreases.

During short circuit the engine proves to be connected to the place of the short circuit through certain external resisting $x_{вн\,2}$, which limits the strength of current $I''_{д}$. Therefore, if resisting $x_{вн\,2}$ is great, then the effect of electric motors on short-circuit current at point K-1 is so insignificantly that it it is possible not to consider.

Incomparably larger effect on the value of ultratransitory short-circuit current in the place of damage have the asynchronous electric motors, connected near the place of damage as for a point K-2 in the diagram of Fig. 6-34b (case $x_{вн2}=0$, i.e. short circuit on the outputs of engine).

The ultratransitory current of three-phase short circuit from asynchronous electric motors with short on their conclusion/output can be determined by the formula:

$$I''_{д}=\frac{E''_{*д}}{x''_{*д}} I_{д.ном}, \qquad (6\text{-}73)$$

where $E''_{*д}$ - emf of electric motors at the initial moment of the short circuit;

$x''_{*д}$ - resisting of electric motors at the same moment of the time;

$I_{д.ном}$ - the rated current of engines.

If is known the starting current of engine, then

$$x''_{*д}=\frac{1}{I_{*пуск}},$$

where

$$I_{*пуск}=\frac{I_{пуск}}{I_{д.ном}}.$$

On the average it is possible to accept $E''_{*д}=0,9$ and $x''_{*д}=0,2$; then

$$I''_{д}=\frac{0,9}{0,2} I_{д.ном}=4,5 I_{д.ном}. \qquad (6\text{-}74)$$

Total value of ultratransitory current in the place of the damage

$$I''=I''_{г}+I''_{д}. \qquad (6\text{-}75)$$

Aperiodic component/term of circuital current of asynchronous

electric motors attenuates so rapidly that during the determination of its impact current they do not consider. Therefore the full/total/complete value of impact current in the place of damage will comprise

$$i_y = k_y \sqrt{2} I''_r + \sqrt{2} I''_x. \qquad (6\text{-}76)$$

During the determination of the effective value of full current during first period I_y and all values of short-circuit current into another point in time the injection of the place of short from induction motors considered should not be.

Thus, during computation I'' and i_y should be considered only the large/coarse electric motors, directly connected near the place of damage. In this case the effect of asynchronous electric motors on the values of short-circuit current indicated especially manifests itself with the large electrical distance of the place of short circuit from fundamental supplies of power (at the high value of resisting $x_{вн1}$ in Fig. 6-34), for example, during determination of I'' and i_y at the secondary voltage of large/coarse industrial substations, in the network 3-6 kV of its own needs of power plants, etc.

To large power motors should be related the engines with a power of 1000 kVA and more. If to one point are connected several engines of smaller power, but in sum they comprise not less than 1000 kVA,

then them should be considered as one engine whose power is equal to the total power of these engines.

6-12. Asymmetric short circuits.

General considerations of the calculation method. During asymmetric short circuits the currents in phases have different value at different angles of displacement between them. Are asymmetric the created by them voltage drops in phases.

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Fundamental means of asymmetric short circuits are two-phase and single-phase short circuits, and also two-phase short circuit to the earth, i.e., closing/shorting between two phases with the simultaneous closing/shorting of the same point to the earth. Single-phase short circuits and two-phase short circuits to the earth are possible only in networks with the neutrals, grounded dead or through comparatively low inductive reactances (reactors), i.e., virtually in networks by voltage 110 kV it is above (see §5-3); single-phase short circuits are possible also in four-wire networks by voltage 380/220 and 220/127 V (between the phase and neutral conductors; see §3-1).

Currents and voltages of asymmetric short circuits most simply are determined with the aid of the method of symmetrical components whose essence consists in the fact that any asymmetric three-phase system of values (currents, voltages, magnetic fluxes, etc.) can be unambiguously decomposed on three balanced systems of values, which are characterized by one from another by value and by sequence (order) of alternating the phases. These symmetrical components of value system are called of straight line (positive), reverse (negative) and null sequences.

The system of forward sequence is of the order of the alternation of phases A, B, C, while the system of backward sequence - respectively reverse order, i.e., A, C, B. The system of null sequence consists of three identical values, cophasal.

The values of the balanced systems of straight/direct, reverse and null sequences accept to designate by indices with respect 1, 2 and 0.

In §6-1 it was indicated that in the practical calculations of currents and voltages during short circuits they proceed from the equality of resisting of phases, i.e., from symmetrical fulfilling of the phases of three-phase circuit.

In such bilateral circuits the Ohm's laws and Kirchhoff can be applied individually to each component of balanced system of values, which considerably simplifies all calculations. The large advantage of the method of symmetrical components short-circuit study is in connection with the fact that it reduces the computation of currents and voltages during asymmetric short circuits to the simple computation of these values during certain conditional (fictitious) three-phase short circuit. Therefore everything presented earlier in the relation to the calculation of currents and voltages during three-phase short circuit is utilized also during the computation of these values during asymmetric closings/shortings.

The bases of the method of symmetrical components are set forth in the course of theoretical electrical engineering [6-4]. Let us recall the briefly basic condition/positions of this method. As it spoke above, any asymmetric system of vectors A, B and C (Fig. 6-35a) it is possible to unambiguously replace with three balanced systems of vectors of the straight line A_1, B_1, by C_1, reverse A_2, B_2, C_2 and for the zero A_0, B_0, C_0 sequences (Fig. 6-35b-d). With respect to this each of the assigned asymmetric vectors A, B and C can be presented in the form of vector sum of its three symmetrical components of straight/direct, reverse and null sequences (Fig. 6-35e):

$$\left.\begin{aligned} \dot{A} &= \dot{A}_1 + \dot{A}_2 + \dot{A}_0; \\ \dot{B} &= \dot{B}_1 + \dot{B}_2 + \dot{B}_0; \\ \dot{C} &= \dot{C}_1 + \dot{C}_2 + \dot{C}_0. \end{aligned}\right\} \qquad (6\text{-}77)$$

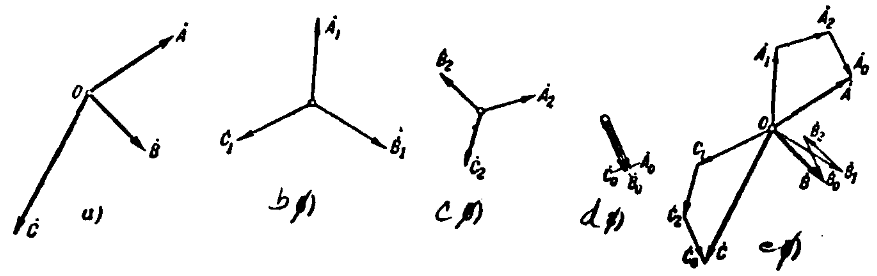

Fig. 6-35. Asymmetric system of three vectors and their symmetrical component.

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From theoretical electrical engineering it is also known [for 6-4] that the multiplication of any vector by the complex number

$$a = e^{j120^\circ} = \cos 120^\circ + j \sin 120^\circ = -\frac{1}{2} + j\frac{\sqrt{3}}{2}$$

is equivalent to the rotation of this vector at an angle of of 120° in clockwise positive of vectors, i.e., counterclockwise. This complex number a, called the operator of phase (or phase factor), is the vector whose modulus/module is equal to one, and argument of 120°.

The multiplication of vector on

$$a^2 = e^{j240^\circ} = -\frac{1}{2} - j\frac{\sqrt{3}}{2}$$

is respectively equivalent to its rotation on 240° in clockwise positive of vectors.

Using the operator of phase, it is possible vectors symmetrical component to express by the vectors of any phase, accepted as basis, for example through the vectors of phase A:

for the vectors of forward sequence

$$\dot{B}_1 = a^2\dot{A}_1 \text{ and } \dot{C}_1 = a\dot{A}_1; \quad (6\text{-}78,a)$$

for the vectors of backward sequence

$$\dot{B}_2 = a\dot{A}_2 \text{ and } \dot{C}_2 = a^2\dot{A}_2; \quad (6\text{-}78,b)$$

for the vectors of the null sequence

$$\dot{A}_0 = \dot{B}_0 = \dot{C}_0. \quad (6\text{-}78,c)$$

Substituting these values in equation (6-77) we obtain:

$$\left.\begin{aligned} \dot{A} &= \dot{A}_1 + \dot{A}_2 + \dot{A}_0; \\ \dot{B} &= a^2\dot{A}_1 + a\dot{A}_2 + \dot{A}_0; \\ \dot{C} &= a\dot{A}_1 + a^2\dot{A}_2 + \dot{A}_0. \end{aligned}\right\} \quad (6\text{-}79)$$

Thus, with the use of method of symmetrical components is sufficient to calculate the values of symmetrical components only for one any phase, for example A, according to which it is already not difficult to define both symmetrical component for two other phases

and full/total/complete values of the corresponding phase values.

As a result of the joint solution of equations (6-79) we obtain the following formulas, which make it possible to determine the symmetrical components of phase A, accepted for the basis:

$$\left.\begin{aligned}\dot{A}_1&=\frac{1}{3}(\dot{A}+a\dot{B}+a^2\dot{C});\\ \dot{A}_2&=\frac{1}{3}(\dot{A}+a^2\dot{B}+a\dot{C});\\ \dot{A}_0&=\frac{1}{3}(\dot{A}+\dot{B}+\dot{C}).\end{aligned}\right\}\quad(6\text{-}80)$$

Being guided by these expressions, is not difficult graphically to define the symmetrical components of the assigned system of vectors as this shown in Fig. 6-36.

Vector sum of the values of forward sequence is equal to zero: $\dot{A}_1+\dot{B}_1+\dot{C}_1=\dot{A}_1+a^2\dot{A}_1+a\dot{A}_1=\dot{A}_1(1+a+a^2)=0$, since $1+a+a^2=1-\frac{1}{2}+j\frac{\sqrt{3}}{2}-\frac{1}{2}-j\frac{\sqrt{3}}{2}=0$. Then is related also to vector sum of the values of backward sequence. Thus, value systems of straight/direct and backward sequences not are only symmetrical, but also are balanced. In contrast to this the balanced system of the values of null sequence is not balanced, since

$$\dot{A}_0+\dot{B}_0+\dot{C}_0=3\dot{A}_0\neq 0.$$

All given equations are valid both for the currents and for voltages during the asymmetric modes/conditions of three-phase installations.

During any asymmetric closing/shorting of phase to the earth (to neutral conductor) the system of phase voltages contains the components of null sequence. In contrast to this the system of interphase voltages is always balanced and the components of null sequence never it contains.

According to (6-80) vector sum of unbalanced system of currents is equal to the triple current of null sequence, flowing in the earth/ground (neutral conductor) in this section of network.

The asymmetric currents, flowing through identical resisting of circuit, create asymmetric voltage drops in the phases which can be decomposed on symmetrical components. In this case a drop in the voltage of forward sequence is created by the current of forward sequence, a drop in the voltage of backward sequence - by a current of backward sequence, etc., i.e., the current of each sequence creates a drop in the voltage of the same sequence.

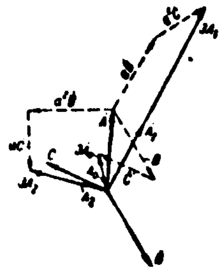

Fig. 6-36. Graphic determination of the symmetrical components of the asymmetric system of vectors A, B and C.

At the same time inductive reactances to the currents of different sequences of one and the same network element can considerably be distinguished by the value (see below). Let us designate through x_1, x_2 and x_0 inductive reactances of the straight/direct, reverse and null sequences of network element with respect to the currents of the corresponding sequences. Then symmetrical component the incidences/drops voltages in network element comprise (phase values):

$$\left.\begin{aligned} \Delta\dot{U}_1 &= \dot{I}_1 j x_1; \\ \Delta\dot{U}_2 &= \dot{I}_2 j x_2; \\ \Delta\dot{U}_0 &= \dot{I}_0 j x_0. \end{aligned}\right\} \qquad (6\text{-}81)$$

In symmetrical ones three-phases circuit it is possible to count, as noted above that the symmetrical components operate independently. This makes it possible to compose separate replacement schemes for each sequence (see Fig. 6-37).

During symmetrical three-phase short circuit voltage in the place of short circuit is equal to zero; during asymmetric short circuits the voltage in the place of closing/shorting not equal to zero is asymmetric.

During calculations of asymmetric short circuits they proceed from the fact that in generators is induced only by emf of forward sequence; whereas the effect of the currents of reverse and null sequences consider by introduction to the calculation of the incidences/drops voltages from the currents indicated in resisting of corresponding sequences of generators. In accordance with this in replacement schemes indicate only emf of forward sequence of power supplies and symmetrical components of voltages in the place of short, but emf of reverse and null sequences consider it equal to zero (Fig. 6-37).

Taking into account the aforesaid above and being guided by second Kirchhoff's law, it is possible to determine the symmetrical components of voltage in the place of short circuiting:

$$\left.\begin{aligned}\dot{U}_{K1}&=\dot{E}-\dot{I}_{K1}jx_{1\,\text{рез}};\\ \dot{U}_{K2}&=0-\dot{I}_{K2}jx_{2\,\text{рез}};\\ \dot{U}_{K0}&=0-\dot{I}_{K0}jx_{0\,\text{рез}},\end{aligned}\right\}\qquad(6\text{-}82)$$

where $\dot{U}_{K1}$, $\dot{U}_{K2}$ and $\dot{U}_{K0}$ - symmetrical component voltages in the place

short circuits;

$\dot{I}_{K1}$, $\dot{I}_{K2}$ and $\dot{I}_{K0}$ - the symmetrical components of current, which flow into the place of the short circuit;

$x_{1\,рез}$, $x_{2\,рез}$ and $x_{0\,рез}$ - resulting resisting of straight/direct, reverse and null sequences of short circuit (switching on power supplies);

$\dot{E}$ - resulting emf of forward sequence of the sources, which feed the short-circuited circuit (phase value).

Familiarization with the given in Fig. 6-37 resulting replacement schemes of three sequences makes it possible to draw the conclusion that the formation of the currents of reverse and null sequences can be considered as the result of the onset in the place of the short circuit of the voltages of the corresponding sequences.

It is clear that in proportion to advance for circuit from the place short to power supplies the voltage of forward sequence grows/rises from $\dot{U}_{K1}$ to $\dot{E}$, and the voltages of reverse and null sequences decrease respectively on $\dot{U}_{K2}$ and $\dot{U}_{K0}$ to zero.

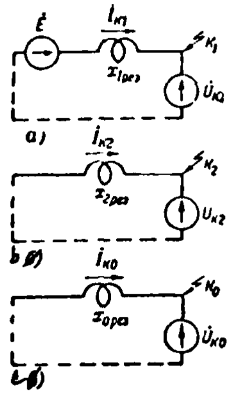

Fig. 6-37. Resulting diagrams of straight line (a), reverse (b) and zero (c) sequences.

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Resisting of different sequences [6-5]. Inductive reactance of forward sequence of any network element, that its inductive reactance during the symmetrical mode/conditions of phases, i.e., the resistance of which previously was accepted during the computation of the currents of three-phase short circuit, since the latter are actually the symmetrical currents of forward sequence.

Inductive reactance of reverse sequence. For those network elements whose mutual induction between phases does not depend on the order of the alternation of phases, inductive reactances of straight/direct and backward sequences are identical, i.e., $x_2=x_1$.

Such elements/cells include air and cable lines, reactors, transformers.

In the rotating machines the currents of backward sequence create the magnetic flux of the stator which rotates against the direction of rotation of the rotor of machine, i.e., it has dual angular velocity with respect to the rotor of machine. This magnetic flux meets on its path somewhat changing reluctance, which depends on the construction/design of machine and which differs from reluctance in the path of the magnetic flux of forward sequence, created with the currents of forward sequence, created with the currents of forward sequence, which rotates synchronously with rotor. Therefore in general for the rotating machines $x_2 \neq x_1$.

Values x_2 of synchronous machines are given in plant informational materials and manuals. In the absence of these data it is possible to take the following average values:

for turbogenerators and salient pole machines with damper windings $x_2 = 1{,}22x''_d$;

for salient pole machines without damper windings $x_2 = 1{,}45x'_d$.

In the approximate practical calculations of asymmetric short

circuits usually for turbogenerators and salient pole machines with damper windings accept $x_2 \approx x_d''$.

Inductive reactance of null sequence. Electrical machines. If the windings of the stator of machine were completely symmetrical, then the magnetic fluxes of the null sequence, created in the windings of three phases of stator by the flowing on them currents of null sequence, completely mutually were cancelled out. However, as a result of certain asymmetry of the stator windings, caused by the design features of machine, full of the compensation for the magnetic fluxes of null sequence it does not occur. By the small value of these uncompensated for magnetic fluxes of null sequence is determined a comparatively small value of inductive reactance of the null sequence of synchronous machines, which usually comprises $x_0 = (0,15—0,6)\ x_d''$.

For the synchronous condensers and large/coarse synchronous electric motors in the absence of plant data it is possible to accept x_2=0.24 and x_0=0.08.

Reactors. As a result of small mutual induction between the coils of reactor, the distance between which is sufficiently great, it is possible approximately to accept $x_0 \approx x_1$.

Aerial lines. After all to the null sequence, which take place in three phases of line, they return to grounded neutrals of the network through the earth/ground (Fig. 6-38a). Inductive reactance of null sequence x_0 of the phase of line is determined by inductive reactance of self-induction x_L of the loop of current "wire-ground" and by inductive reactances of mutual induction x_M of the wire of this phase with the wires of other two phases:

$$x_0 = x_L + 2x_M$$

(on air electric power lines they fulfill the transposition of wires, which makes it possible to take identical value x_M for any pair of wires).

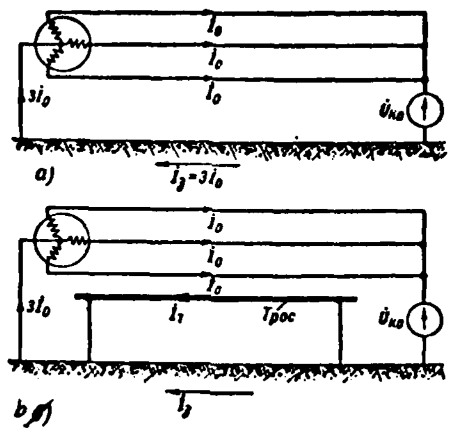

Fig. 6-38. Course of the currents of null sequence in line. a) without cable on the line; b) with cable on line.

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The depth of the course of terrestrial current depends on its conductivity: in well conducting soil the terrestrial current flows/occurs/lasts at the comparatively small depth; on the contrary, in the badly/poorly carrying out soil (granite, scales, etc.) the current flows/occurs/lasts at considerably larger depth. With an increase of the depth of the course of terrestrial current increase the width of the loop of current the wire - earth/ground and its inductance and, consequently, also resistance of the null sequence of line.

Thus, resisting of the null sequence of line depends on ground conductivity.

If line is shielded from the direct impacts of lightning by ground wire (or cables), then inverse current by part flows/occurs/lasts in the earth/ground, and by part the cable (Fig. 6-38b). The separation and cable is considerably lower than the distance from wires to terrestrial current; therefore the inductance of loop wire - it increased less than the inductance of loop wire - the earth/ground. As a result this presence of ground wire it leads to the decrease of inductive reactance of the null sequence of line.

With the decrease of the effective resistance of ground wire increases the share of inverse current in it, which leads to the decrease of inductive reactance of the null sequence of line. Steel cables virtually little affect value x_0 of line. Cables from the well carrying out metals (steel-aluminum, copper) considerably decrease x_0 the lines.

Inductive reactance of the null sequence of the twin-circuit lines somewhat more than singe-circuit ones, as a result of the inductive effect of the currents of null sequence, flowing in the wires of adjacent circuit.

In the approximate computations of short-circuit currents it is possible to take the corrected below average/mean values of x_0 aerial lines (with $x_1=x_2\approx0.4$ Ω/km):

for lines without cables or with steel cables:

singe-circuit ... $x_0=1.4$ Ω/km

twin-circuit ... $x_0=2.2$ Ω/km.

for lines with cables from the well carrying out metal:

singe-circuit ... $x_0=0.8$ Ω/km.

twin-circuit ... $x_0=1.2$ Ω/km.

Power cables. In approximate computations for power cables it is possible to accept $x_0=(3.5\text{-}4.6)x_1$.

Power transformers. Inductive reactance of the null sequence of transformers depends on their construction/design and diagram of connection of windings.

Let us first of all note that the currents of null sequence

cannot flow/occur/last through the windings of transformers, connected into star without the grounding of neutral or without neutral conductor, since the sum of the currents of the null sequence of three phases $3I_0$ is not equal to zero, which is compulsory for the currents, flowing through the star without grounded neutral or without neutral conductor.

If line concludes with the winding of transformer, connected into triangle, then along this line also cannot flow/occur/last the currents of null sequence.

Thus, if the voltage of null sequence is applied to the windings, connected into star without the grounding of neutral or without neutral conductor or by that connected into triangle, then in these windings of the currents of null sequence it does not appear and inductive reactance of null sequence is equal to infinity ($x_0=\infty$).

The finite value x_0 can be only with appendix of the voltage of null sequence from the side of the winding of transformer, connected into star with grounded neutral or neutral conductor.

Fig. 6-39 gives the diagrams of connection of windings and substitution for the currents of the null sequence of the most widely used double wound and triple-wound transformers.

For all transformers independent of type and construction/design with the connection of windings on diagram Y_0/Δ (Fig. 6-39a) inductive reactance of the null sequence

$$x_0 = x_I + x_{II} = x_I.$$

In secondary winding of transformer is induced emf of null sequence, and since the phases of winding are connected into triangle, then in them appear the currents of the null sequence, which do not emerge beyond the limits of triangle. Thus, entire/all induced in secondary winding emf of null sequence is expended/consumed on conducting of the current of null sequence in resisting of secondary winding x_{II}.

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In replacement scheme the aforesaid is reflected/represented by the conditional grounding of the end/lead of branch x_{II} and by the cutoff/disconnection of the external secondary circuit (grounding of the end/lead of branch x_{II} shows that this with branch concludes the path of the current of null sequence).

Inductive reactance of the null sequence of three-phase groups of single-phases transformer and three-phase four-rod and shell-type

transformers should be accepted:

with the connection of windings Y_0/Y_0 (Fig. 6.39b) $x_0=x_1$.

with the connection of windings Y_0/Y (Fig. 6.39c) $x_0=\infty$.

For three-phase tripivotal transformers with the connection of windings Y_0/Y one should accept $x_0 = x_1 + x_{\mu_0}$, and with the connection of windings Y_0/Y_0 should be utilized a full/total/complete replacement scheme in Fig. 6.39b, where x_{μ_0}, that depending on the construction/design of transformer, lies/rests within limits $x_{\mu_0} = 0.3-1.0$, and winding impedances accept $x_I = x_{II} = 0.5u_k$.

Replacement schemes for the currents of the null sequence of triple-wound transformers are given in Fig. 6.39d-f. Resistance of separate windings x_B, x_C, x_H determine from formulas (6-14).

Instructions on the construction of the diagrams of separate sequences. The diagram of forward sequence is comprised just as replacement scheme during the computation of the currents of three-phase short circuit (Fig. 6-40b).

The diagram of backward sequence is comprised from the same elements/cells, as the diagram of forward sequence, since the

currents of straight/direct and backward sequences flow/occur/last over one and the same paths. The electromotive forces of backward sequence of power supplies are accepted as the equal to zero; therefore by the beginning of the diagram of backward sequence is the point, which unites the beginnings of all generator branches, and the end/lead of the diagram - the point of short circuit, at which is applied the voltage of backward sequence, emergent due to the asymmetry of short circuit (Fig. 6-40c).

The diagram of null sequence differs from the diagrams of straight/direct and backward sequences, since the currents of null sequence flow/occur/last over the paths, distinct from the paths of the course of the currents of three-phase short circuit. The currents of null sequence flow/occur/last over three phases and return through the earth/ground, ground wires of aerial lines, metal cable sheathings, etc.

Beginning the composition of the diagram of null sequence, it is first of all necessary to establish/install the possible outlines of the course of the current of null sequence. For forming such outlines it is necessary that in the circuit, electrically connected with the place of short circuit, would be grounded neutrals. With several grounded neutrals, electrically connected, the currents of null sequence branch between them.

Diagram null sequence they begin to be from the point of short circuit, assuming that in it three phases short-circuited. The ends/leads of the elements of the network of the null sequence, through which return the currents of zero sequence, have potential of the earth/ground. Therefore it is possible to combine them into one common point, which is the beginning of the diagram of the null sequence; the end/lead of this diagram is considered the point of short circuit (Fig. 6-40d).

If neutral is grounded through resisting, then it should be introduced into the replacement scheme of null sequence by the triple value. Is explained this by the fact that the diagram of null sequence they compose for one phase, and through resisting in neutral flows/occurs/lasts the sum of the currents of the null sequence of three phases. In order to consider a real voltage drop in this resisting, it must be increased 3 times.

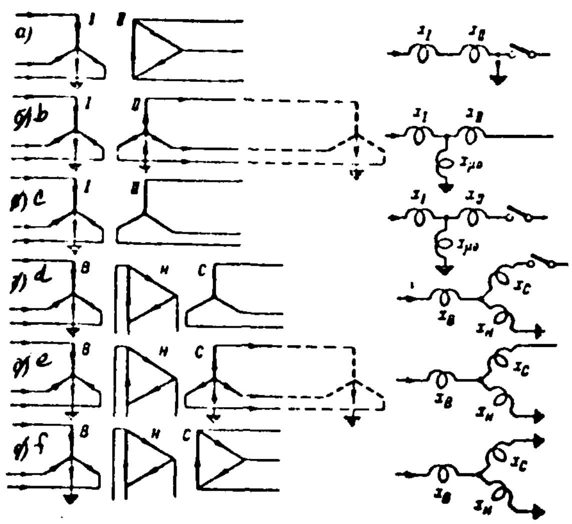

Fig. 6-39. Replacement schemes of transformers for the currents of null sequence.

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In the form of an example in Fig. 6-40 they are given network of the simplest installation and replacement scheme of its for all sequences during asymmetric short circuit at point K. The first numeral of index in resisting indicates the sequence of resisting, and the second - reference number of element/cell in network of installation.

Resulting resisting of the diagrams of separate sequences determine with the aid of the same receptions/procedures the conversions of the diagrams which were utilized earlier during the computation of the currents of three-phase short circuit.

If for the rotating machines accept $x_2=x_1$, then $x_{2pes}=x_{1pes}$ it is possible to be restricted to the composition only of two diagrams - straight/direct and null sequences.

Currents and voltages in the place of asymmetric short circuit [6-5]. Let us agree to consider that for the given point of short circuit the diagrams of separate sequences are already given to the simplist form and to us are known resulting emf of supplies of power $\dot{E}$ (phase value) and resulting resisting of entire short circuit x_{1pes}, x_{2pes} and x_{0pes} (Fig. 6-40).

Furthermore, for simplification in further linings/calculations let us agree to examine short circuit on certain conditional branching resisting of phases of which are equal to zero. Currents in the phases of this branching are currents in the place of short circuit. For positive direction of flow we accept their direction to the place of short circuit.

Two-phase short circuit. If we assume the two-phase short

circuit between phases B and C (Fig. 6-41a), then for the branching of short circuit it is possible to write the following obvious conditions:

$$\dot{I}^{(2)}_{KA}=0;\ \dot{I}^{(2)}_{KB}=-\dot{I}^{(2)}_{KC};\ \dot{U}^{(2)}_{KB}-\dot{U}^{(2)}_{KC}=0.$$

Furthermore, since two-phase short circuit is balanced, then $\dot{I}_{KO}=0$ and $\dot{U}_{KO}=0.$

After accepting phase A for calculation, it is possible, being guided by formulas (6-77), to write:

$$\dot{I}^{(2)}_{KA}=\dot{I}^{(2)}_{KA1}+\dot{I}^{(2)}_{KA2}=0,$$

whence

$$\dot{I}^{(2)}_{KA1}=-\dot{I}^{(2)}_{KA2}.$$

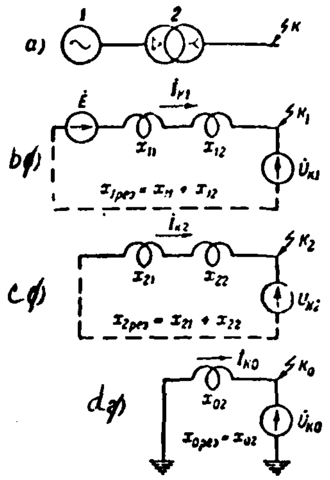

Fig. 6-40. Example of the composition of the replacement schemes of separate sequences.

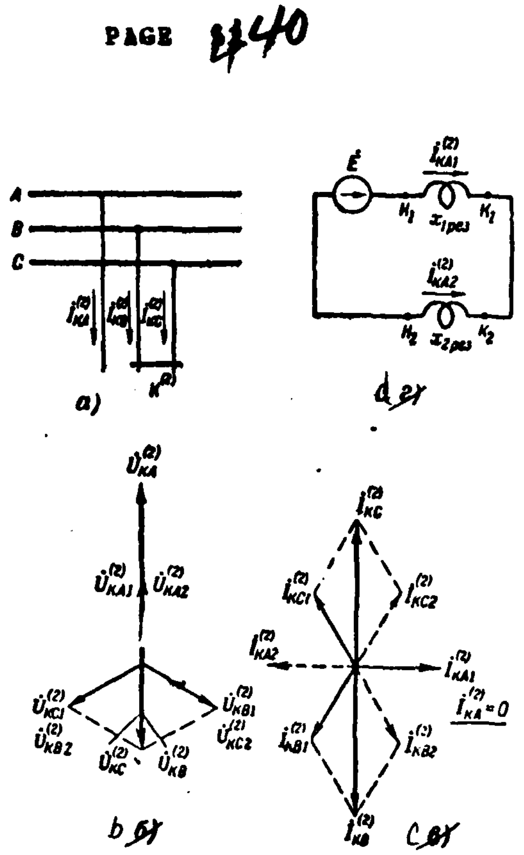

Fig. 6-41. Two-phase short circuit.

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Utilizing formula (6-80) and taking into account that $\dot{U}^{(2)}_{KB}=\dot{U}^{(2)}_{KC}$, is easy to establish/install the equality of the symmetrical components of voltage in the place of the short circuit:

$$\dot{U}^{(2)}_{KA1}=\dot{U}^{(2)}_{KA2}.$$

In accordance with this and on the basis of formulas (6-82) it is possible to write

$$\dot{E}-\dot{I}^{(2)}_{KA1}\,jx_{1\,\text{рез}}=-\dot{I}^{(2)}_{KA2}\,jx_{2\,\text{рез}}=\dot{I}^{(2)}_{KA1}\,jx_{2\,\text{рез}},$$

whence we obtain:

$$\dot{I}^{(2)}_{KA1} = \frac{\dot{E}}{j(x_{1\,рез} + x_{2\,рез})}. \qquad (6\text{-}83)$$

It is now not difficult, using formulas (6-79), to determine short-circuit currents in the damaged phases:

$$\dot{I}^{(2)}_{KB} = a^2 \dot{I}^{(2)}_{KA1} + a\dot{I}^{(2)}_{KA2} = (a^2 - a)\dot{I}^{(2)}_{KA1} = \\ = -j\sqrt{3}\,\dot{I}^{(2)}_{KA1}$$

and analogously

$$\dot{I}^{(2)}_{KC} = j\sqrt{3}\,\dot{I}^{(2)}_{KA1}.$$

Thus, the absolute value of short-circuit current in the damaged phases:

$$I^{(2)}_{K} = \sqrt{3}\,I^{(2)}_{K1} = \frac{\sqrt{3}\,E}{x_{1\,рез} + x_{2\,рез}}. \qquad (6\text{-}84)$$

Symmetrical component voltages in the place short circuits it is possible to determine, utilizing formulas (6-82):

$$\dot{U}^{(2)}_{KA1} = \dot{E} - \dot{I}^{(2)}_{KA1}\,jx_{1\,рез} = \dot{I}^{(2)}_{KA1}\,jx_{2\,рез};$$
$$\dot{U}^{(2)}_{KA2} = -\dot{I}^{(2)}_{KA2}\,jx_{2\,рез} = \dot{I}^{(2)}_{KA1}\,jx_{2\,рез} = \dot{U}^{(2)}_{KA1}.$$

According to formulas (6-79) we determine the phase values of voltages in the place of the short circuit:

$$\left.\begin{aligned} \dot{U}^{(2)}_{KA} &= 2\dot{I}^{(2)}_{KA1}\,jx_{2\,рез}; \\ \dot{U}^{(2)}_{KB} &= \dot{U}^{(2)}_{KC} = -\frac{1}{2}\dot{U}^{(2)}_{KA}. \end{aligned}\right\} \qquad (6\text{-}85)$$

Utilizing the obtained relationships/ratios, it is possible to construct vector diagrams of currents and voltages in the place of short circuit. Knowing $\dot{U}^{(2)}_{KA1}$ and $\dot{U}^{(2)}_{KA2}$, are constructed to scale the

star of the vectors of the voltages of forward sequence $\dot{U}^{(2)}_{KA1}, \dot{U}^{(2)}_{KB1}, \dot{U}^{(2)}_{KC1}$ and the star of the vectors of the voltages of backward sequence $\dot{U}^{(2)}_{KA2}, \dot{U}^{(2)}_{KC2}, \dot{U}^{(2)}_{KB2}$ (Fig. 6-40b). Vector sum of the vectors of voltages $\dot{U}^{(2)}_{KA1}$ and $\dot{U}^{(2)}_{KA2}$ gives the vector of phase voltage $\dot{U}^{(2)}_{KA}$ of the intact/uninjured/undamaged phase A.

Respectively vector sums of vectors $\dot{U}^{(2)}_{KB1}$ and $\dot{U}^{(2)}_{KB2}$ and vectors $\dot{U}^{(2)}_{KC1}$ and $\dot{U}^{(2)}_{KC2}$ give the vectors of phase voltages $\dot{U}^{(2)}_{KB}$ and $\dot{U}^{(2)}_{KC}$ of the damaged phases B and C.

It is analogous in known magnitude of vector of currents $\dot{I}^{(2)}_{KA1}$ and $\dot{I}^{(2)}_{KA2}$ are constructed two stars of the vectors of currents straight/direct and backward sequences (Fig. 6-41c). Vector sum of the currents of straight/direct and backward sequences in phases gives current in intact/uninjured/undamaged phase $\dot{I}^{(2)}_{KA}=0,$ and in damaged phases $\dot{I}^{(2)}_{KB}$ and $\dot{I}^{(2)}_{KC}$, which are out of phase on 180°.

Analogously it is possible to construct vector diagrams of voltages and currents during the short circuit between any two phases.

Above it was shown that during two-phase short circuit $\dot{U}^{(2)}_{KA1}=\dot{U}^{(2)}_{KA2}$. This makes it possible to combine the ends/leads of the diagrams of straight/direct and backward sequences as shown in Fig.

6-41d, as a result of which is obtained the so-called composite diagram of two-phase short circuit, which completely corresponds to all brought-out above relationships/ratios, which characterize two-phase short circuit.

Single-phase short circuit to the earth, for example phase A (Fig. 6-42a), is characterized by the following obvious conditions:

$$\dot{I}^{(1)}_{KB}=0;\ \dot{I}^{(1)}_{KC}=0;\ \dot{U}^{(1)}_{KA}=0.$$

After accepting phase A for calculation, it is possible, being guided by formulas (6-80), to write:

$$\dot{I}^{(1)}_{KA1}=\dot{I}^{(1)}_{KA2}=\dot{I}^{(1)}_{KA0}=\frac{1}{3}\dot{I}^{(1)}_{KA}.$$

On the basis of formula (6-79) and initial condition it is possible also to write:

$$\dot{U}^{(1)}_{KA}=\dot{U}^{(1)}_{KA1}+\dot{U}^{(1)}_{KA2}+\dot{U}^{(1)}_{KA0}=0.$$

If we substitute here the values of the symmetrical components of voltage in the place of short circuit according to formulas (6-82) and to replace the currents of all sequences through the current of forward sequence, then we will obtain:

$$\dot{E}-\dot{I}^{(1)}_{KA1}j\,(x_{1\,рез}+x_{2\,рез}+x_{0\,рез})=0,$$

whence:

$$\dot{I}^{(1)}_{KA1}=\frac{\dot{E}}{j\,(x_{1\,рез}+x_{2\,рез}+x_{0\,рез})}. \qquad (6\text{-}86)$$

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Absolute value of short-circuit current in the damaged phase:

$$I_K^{(1)} = 3I_{K1}^{(1)} = \frac{3E}{x_{1\,\text{рез}} + x_{2\,\text{рез}} + x_{0\,\text{рез}}}. \quad (6\text{-}87)$$

Symmetrical component voltages in place short circuits are determined from formulas (6-82):

$$\left.\begin{aligned} \dot{U}_{KA1}^{(1)} &= \dot{E} - \dot{I}_{KA1}^{(1)} jx_{1\text{рез}} = \dot{I}_{KA1}^{(1)} j(x_{2\,\text{рез}} + x_{0\,\text{рез}}); \\ \dot{U}_{KA2}^{(1)} &= -\dot{I}_{KA2}^{(1)} jx_{2\,\text{рез}} = -\dot{I}_{KA1}^{(1)} jx_{2\,\text{рез}}; \\ \dot{U}_{KA0}^{(1)} &= -\dot{I}_{KA0}^{(1)} jx_{0\,\text{рез}} = -\dot{I}_{KA1}^{(1)} jx_{0\,\text{рез}}. \end{aligned}\right\} \quad (6\text{-}88)$$

The full/total/complete phase values of voltages in the place of short circuit can be determined according to formulas (6-79).

On the basis of the obtained relationships/ratios it is possible to construct vector diagrams of currents and voltages in the place of short circuit (Fig. 6-42b and c).

The composite diagram, which satisfies all relationships/ratics during single-phase short circuit, is given in Fig. 6-42d.

Two-phase short circuit to the earth between phases, for example B and C, with simultaneous closing/shorting to the earth at the same point (Fig. 6-43a) is characterized by the following obvious conditions:

$$\dot{I}_{KA}^{(1,1)} = 0; \ \dot{U}_{KB}^{(1,1)} = 0; \ \dot{U}_{KC}^{(1,1)} = 0.$$

Supplementary conditions, as this was accepted above in the

examination of other means of asymmetric short circuits, are fundamental equations (6-77), (6-79), (6-80) and (6-82) the method of symmetrical components. Accepting as calculated phase A and omitting all conclusion/output, let us give the directly final formulas, making it possible to determine currents and voltages with the means of short circuit in question.

The symmetrical components of current in the place of the short circuit

$$\left.\begin{aligned} I_{KA1}^{(1,1)} &= \frac{\dot{E}}{j\left(x_{1pes} + \frac{x_{2pes}x_{0pes}}{x_{2pes} + x_{0pes}}\right)}; \\ I_{KA2}^{(1,1)} &= -I_{KA1}^{(1,1)} \frac{x_{0pes}}{x_{2pes} + x_{0pes}}; \\ I_{KA0}^{(1,1)} &= -I_{KA1}^{(1,1)} \frac{x_{2pes}}{x_{2pes} + x_{0pes}}. \end{aligned}\right\} \quad (6\text{-}89)$$

Absolute value of the current of straight/direct sequence in the place of the short circuit:

$$I_{K1}^{(1,1)} = \frac{E}{x_{1pes} + \frac{x_{2pes}x_{0pes}}{x_{2pes} + x_{0pes}}} \quad (6\text{-}90)$$

and currents in the damaged phases

$$I_K^{(1,1)} = \sqrt{3}\sqrt{1 - \frac{x_{2pes}x_{0pes}}{(x_{2pes} + x_{0pes})^2}}\, I_{K1}^{(1,1)}. \quad (6\text{-}91)$$

Current, which returns through the earth/ground:

$$I_3^{(1,1)} = 3I_{K0}^{(1,1)} = 3I_{K1}^{(1,1)} \frac{x_{2pes}}{x_{2pes} + x_{0pes}}. \quad (6\text{-}92)$$

Symmetrical component voltages in the place short circuits:

$$\dot{U}_{KA1}^{(1,1)} = \dot{U}_{KA2}^{(1,1)} = \dot{U}_{KA0}^{(1,1)} = I_{KA1}^{(1,1)} j \frac{x_{2pes}x_{0pes}}{x_{2pes} + x_{0pes}}. \quad (6\text{-}93)$$

The total voltage of intact/uninjured/undamaged phase in the place of the short circuit

$$\dot{U}_{KA}^{(1,1)} = 3\dot{U}_{KA1}^{(1,1)}. \qquad (6\text{-}91)$$

Vector diagrams of currents and voltages are given in Fig. 6-43b and c.

Composite diagram is given in Fig. 6-43d.

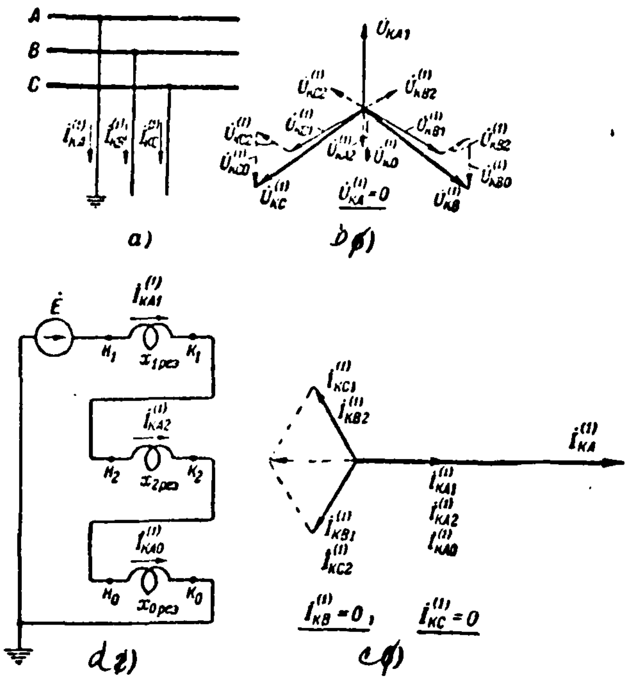

Fig. 6-42. Single-phase short circuit.

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Generalized formulas for determining the currents during asymmetric short circuits. From the examination of formulas (6-84), (6-87) and (6-91) it is evident that the absolute value of current with any means of short circuit is proportional to the current of forward sequence in the place of short circuit and can be determined from the following general/common/total expression:

$$I_K^{(n)} = m^{(n)} I_{K1}^{(n)}, \qquad (6\text{-}95)$$

where $m^{(n)}$ - the proportionality factor, depending on means of the short circuit (see Table 6-2);

$I_{K1}^{(n)}$ - current of forward sequence for the means of short circuit in question.

The analysis of the structure of formulas (6-83), (6-86) and (6-90) allows for determining the absolute value of the current of forward sequence in the place of short circuit to accept also the general/common/total expression:

$$I_{K1}^{(n)} = \frac{E}{x_{1рез} + x_{доп}^{(n)}} = \frac{E}{x_{рез}^{(n)}}, \qquad (6\text{-}96)$$

where $x_{доп}^{(n)}$ - supplementary inductive reactance, introduced into the diagram of forward sequence whose value depends on means of short circuit and is determined only by values $x_{2рез}$ and $x_{0рез}$ (see Table 6-2);

$x_{рез}^{(n)} = x_{1рез} + x_{доп}^{(n)}$ - resulting resistance for this means of asymmetric short circuit with which the latter is replaced by certain conditional three-phase short circuit, distant from the real point of short (in the diagram of forward sequence) to supplementary inductive reactance $x_{доп}^{(n)}$;

Thus, the current of forward sequence during any asymmetric short circuit is defined as the current of certain conditional three-phase short circuiting after resistance $x^{(n)}_{\text{рез}}$.

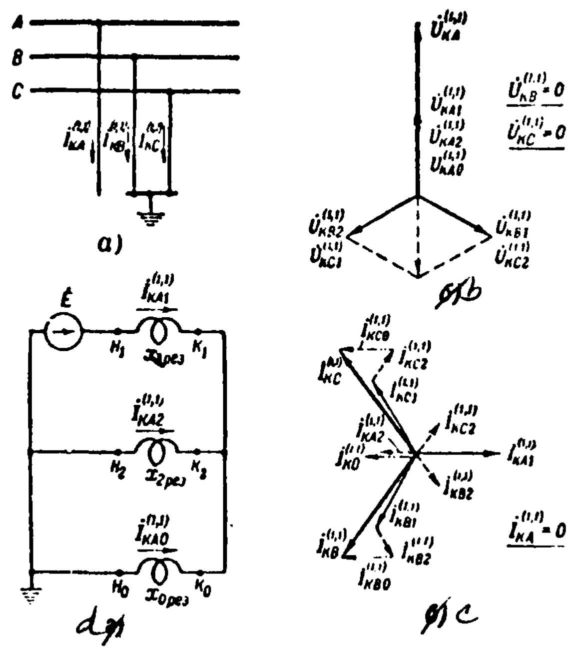

Fig. 6-43. Two-phase short circuit to the ground.

Table 6-2. Values $x_{\text{доп}}^{(n)}$ and $m^{(n)}$ for different means of short circuit.

(1) Вид короткого замыкания	(2) Индекс короткого замыкания (n)	$x_{\text{доп}}^{(n)}$	$m^{(n)}$
(3) Трехфазное	(3)	0	1
(4) Двухфазное	(2)	$x_{2\,\text{рез}}$	$\sqrt{3}$
(5) Однофазное	(1)	$x_{2\,\text{рез}}+x_{0\,\text{рез}}$	3
(6) Двухфазное на землю .	(1, 1)	$\frac{x_{2\,\text{рез}}\,x_{0\,\text{рез}}}{x_{2\,\text{рез}}+x_{0\,\text{рез}}}$	$\sqrt{3}\sqrt{1-\frac{x_{2\,\text{рез}}\,x_{0\,\text{рез}}}{(x_{2\,\text{рез}}+x_{0\,\text{рез}})^2}}$

Key: (1). Means of short circuit. (2). Index of short circuit (n). (3). Three-phase. (4). Two-phase. (5). Single-phase. (6). Two-phase to the ground.

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Let us note that $x_{\text{доп}}^{(n)}$ at the point in question remains constant/invariable for entire process of short circuit.

Determination of ultratransitory and impact currents during asymmetric short circuits. In §6-6 it was indicated that in practical calculations usually accept $E''=kU_{cp}$ (value of coefficient of k they are given to §6-6 and Table 6-1). Therefore substituting in formula (6-96)

$$E=\frac{kU_{cp}}{\sqrt{3}}$$

and taking into account formula (6-95), we obtain the following calculated expressions for determining the component of forward sequence and full of value ultratransitory current in the place of the short circuit:

$$I_1''^{(n)}=\frac{kU_{cp}}{\sqrt{3}(x_{1\text{рез}}+x_{\text{доп}}^{(n)})}=\frac{kU_{cp}}{\sqrt{3}\,x_{\text{рез}}^{(n)}} \quad (6\text{-}97)$$

and

$$I''^{(n)}=m^{(n)}\frac{kU_{cp}}{\sqrt{3}\,x_{\text{рез}}^{(n)}}, \quad (6\text{-}98)$$

where $x_{1\text{рез}}$, $x_{\text{доп}}^{(n)}$ and $x_{\text{рез}}^{(n)}$ are expressed in ohms and are referred to voltage U_{cp}.

If all resisting are expressed in relative unity and are referred to base line power $S_б$, then the component of forward sequence of ultratransitory current in the place of short circuit can be determined according to formula, analogous formula (6-58):

$$I_1''^{(n)}=\frac{k}{x_{*1рез}+x_{*доп}^{(n)}}I_б=\frac{k}{x_{*рез}^{(n)}}I_б, \quad (6\text{-}99)$$

and the full of of ultratransitory current

$$I''^{(n)}=m^{(n)}\frac{k}{x_{*рез}^{(n)}}I_б, \quad (6\text{-}100)$$

where

$$I_б=\frac{S_б}{\sqrt{3}U_{ср}}.$$

Impact current is determined from the formula, analogous (6-59):

$$i_y^{(n)}=k_y\sqrt{2}\,I''^{(n)}. \quad (6\text{-}101)$$

Instructions on values k_y were given into §6-6.

Determination of the current of asymmetric short circuit at any moment of time. Calculated curves (Fig. 6-25 and 6-26), constructed for three-phase short circuit, can be utilized also for determining the currents of forward sequence of any asymmetric short circuit. As has already been indicated, any asymmetric short circuit is reduced to conditional three-phase short after resulting resisting $x_{рез}^{(n)}=x_{1рез}+x_{доп}^{(n)}$. Therefore if we determine calculated resisting of conditional three-phase short

$$x_{*расч}^{(n)}=(x_{*1рез}+x_{*доп}^{(n)})\frac{S_{ном\Sigma}}{S_б},$$

then by obtained value $x^{(n)}_{*\text{расч}}$ and by calculated curve for corresponding to time t is determined the relative value of the current of forward sequence for this means of short circuit $I^{(n)}_{*1t}$.

Then current in the damaged phase comprises

$$I^{(n)}_{t}=m^{(n)}I^{(n)}_{*1t}I_{\text{ном}\Sigma}, \qquad (6\text{-}102)$$

where

$$I_{\text{ном}\Sigma}=\frac{S_{\text{ном}\Sigma}}{\sqrt{3}U_{\text{ср}}}.$$

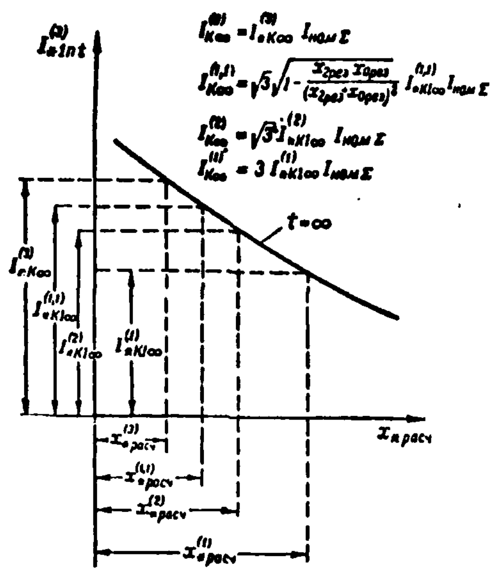

Fig. 6-44. To the explanation of the determination of the steady currents of asymmetric short circuits from calculated curve for t=∞.

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Fig. 6-44 shows determination from calculated curve t=∞ of the steady current in the various forms of asymmetric short circuit.

Entire presented into §6-9 in the relation to the computation of short-circuit currents taking into account different distance of power supplies from the place of short circuit completely is propagated also to asymmetric short circuits. One should only remember that calculated resisting of circuits must be determined taking into account supplementary inductive reactance $x^{(n)}_{доп}$ for the appropriate means of short circuit, i.e., to substitute in formulas (6-69) $x^{(n)}_{рез}=x_{1рез}+x^{(n)}_{доп}$. Let us note also that since any asymmetric short circuit is considered as the three-phase short circuit, distant to supplementary resisting $x^{(n)}_{доп}$, then distribution coefficients C, computed from formulas (6-67) and (6-68), where enter resisting of the branches of the diagram of forward sequence, they do not depend on means of short circuit and for this point of short circuit they remain constant/invariable for all means of short circuit.

The relationship/ratio between the currents of various means of short circuit at the initial moment of short is easy to find on the basis of formula (6-98) or (6-100). So, the comparison of ultratransitory currents with two- and three-phase short circuits gives:

$$\frac{I''^{(3)}}{I''^{(2)}}=\frac{m^{(3)}(x_{1\text{рез}}+x_{2\text{рез}})}{m^{(2)}x_{1\text{рез}}}.$$

In practical calculations usually accept $x_{2\text{рез}}=x_{1\text{рез}}$, therefore

$$\frac{I''^{(3)}}{I''^{(2)}}=\frac{2}{\sqrt{3}}\ \overset{(1)}{\text{или}}\ I''^{(2)}=0{,}87\,I''^{(3)}.$$

Key: (1). or.

Since $i_y\equiv I''$, that:

$$\frac{i_y^{(3)}}{i_y^{(2)}}=\frac{2}{\sqrt{3}}=1{,}15, \qquad (6\text{-}103)$$

i.e. impact current is more during three-phase short circuit. Therefore henceforth let us determine only impact current with this means of short circuit.

The strengths of steady currents with two- and three-phase short circuits are also different. In the case of the small electrical distance of the place of short circuit from generators a difference in steady currents two- and three-phase short circuits in essence is determined by the different values of the reaction of stator with these means of damages. It is known that the relationship/ratio of

magnetizing force of the reaction of stator with two- and three-phase short circuits comprises:

$$\mathcal{F}_a^{(3)} : \mathcal{F}_a^{(2)} = \sqrt{3} : 1.$$

In accordance with this the relationship/ratio between the steady currents during short circuit on the terminals/grippers:

the turbogenerators $I_\infty^{(2)} : I_\infty^{(3)} \approx 1,5;$

the hydraulic generators $I_\infty^{(2)} : I_\infty^{(3)} \approx 1,1.$

$(x_{*расч}^{(3)} > 3)\ I_\infty = I''$,

During short circuit at distant point therefore at this point the relationship/ratio between the steady currents with two- and three-phase short circuits will be:

$$\frac{I_\infty^{(3)}}{I_\infty^{(2)}} = \frac{I''^{(3)}}{I''^{(2)}} = \frac{2}{\sqrt{3}}.$$

Thus, during short circuit on the terminals/grippers of generator and at the points of network from small electrical distance $I_\infty^{(2)} > I_\infty^{(3)}$, and during short circuit at distant point $I_\infty^{(2)} < I_\infty^{(3)}$.

Is explained this by the fact that with an increase in the distance of the point of short circuit by the value of short-circuit current increasingly less manifest themselves transient electromagnetic processes in the generators of stations (change of reacting the stator) and increasingly value of short-circuit current

it is determined by inductive reactance of circuit. During short circuit at the distant point it is possible, as it spoke earlier, to consider that there are no transient electromagnetic processes in generator, voltage on its terminals/grippers remains constant in the process of short circuit and the value of short-circuit current is dete...ined only by resisting of circuit to the place of damage.

From the aforesaid it follows that at certain value $x^{(3)}_{*расч}$ of circuit must occur condition $I^{(3)}_{\infty}=I^{(2)}_{\infty}$. Such resisting is $x^{(3)}_{*расч}\approx 0{,}6$.

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Therefore tentatively it is possible to consider that if $x^{(3)}_{*расч}<0{,}6$, then $I^{(2)}_{\infty}>I^{(3)}_{\infty}$, and if $x^{(3)}_{*расч}>0{,}6$, then $I^{(2)}_{\infty}<I^{(3)}_{\infty}$. Hence it is possible to draw the conclusion that the steady current during two-phase short circuit should be determined only when $x^{(3)}_{*расч}<0{,}6$.

In the Soviet installations of high voltage the dead ground of neutrals is applied only in networks by voltage 110 kV even above, that feed through transformers. Therefore single-phase short circuits, as a rule, have sufficiently large distance from the generators of stations. Detailed analysis of single-phase short circuits is shown [6-5] that in the networks indicated depending on relation $\frac{x_{0рез}}{x_{1рез}}$ can occur the following relationships/ratios of the

currents of the single-phase and three-phase short circuits:

$$\frac{I_K^{(1)}}{I_K^{(3)}} < 1,5.$$

At the same time in networks voltage 110 kV and above take measures to the limitation of the current of single-phase short circuit by the value, which does not exceed the current of three-phase short circuit. Is reached this either by ungrounding the part of the neutrals of transformers or via the grounding of the part of the neutrals through inductive reactances.

During two-phase short circuit to the earth current $I_K^{(1,1)}$ can exceed current $I_K^{(3)}$ is not more than $\sqrt{3}$ once. For current $I_K^{(1,1)}$ to the value, which does not exceed current $I_K^{(3)}$, are utilized the same measures, as for decreasing the single-phase short-circuit currents.

Determination of currents in the branches of diagram. For determining the current in the separate branches of diagram it is necessary to, first of all, find the distribution of previously calculated symmetrical components of current in the branches of the diagrams of the corresponding sequences. Then either according to formulas (6-79), or by the construction of vector diagram of the currents (which is simpler) determine real currents in branches diagrams.

Let us note that in the diagrams of reverse and null sequences to more conveniently find relative current distribution, accepting the current of the datum of sequence in the place of short for unity. The advantage of relative current distribution in the fact that it does not depend on the form of short and moment of time of the process of short.

If in the short-circuited circuit are transformers with the connection of windings Y/Δ or Δ/Y, then the taking place through them currents of straight/direct and backward sequences obtain angular displacement on 30° (for greater detail, see [6-5]).

Determination of voltages at different points of diagram. Symmetrical component voltages at any point diagrams during asymmetric short circuit are defined as vector sum of the voltage of the datum of sequence in the point of short circuit and impact in the voltage of the same sequence in section from this point to the place of the short circuit:

$$\left.\begin{aligned}\dot{U}_1&=\dot{U}_{K1}+\dot{I}_1 jx_1;\\ \dot{U}_2&=\dot{U}_{K2}+\dot{I}_2 jx_2;\\ \dot{U}_0&=\dot{U}_{K0}+\dot{I}_0 jx_0,\end{aligned}\right\} \quad (6\text{-}104)$$

where $\dot{U}_{K1}$, $\dot{U}_{K2}$ and $\dot{U}_{K0}$ - symmetrical component voltages in the place short circuits, determined according to formulas (6-82): $\dot{I}_1$, $\dot{I}_2$, $\dot{I}_0$ and x_1, x_2, x_0 - respectively currents and resisting of

straight/direct, reverse and null sequences in the section between this point and place of short circuit.

Real phase voltages in the assigned to point diagram determine from formulas (6-79) or by the construction of vector diagram, which is simpler.

One should consider that the transformers with the diagrams of connection Y/Δ create the supplementary shift/shear of the vectors of voltages on angle of 30° (see [6-5]).

Example of 6-12. To determine ultratransitory current in the various forms of short circuit at point K of diagram in Fig. 6-40.

Is assigned: the turbogenerator with a power of 235 MVA; $x''_{*d}=0,18$;

transformer 240 MVA; $u_к=10,5\%$;

the medium voltage of the step/stage of short circuit $U_{ср}=115$ kV.

We accept $S_б=S_{г.ном}=235$ MVA; $U_б=U_{ср}$ =115 kV; then

$$I_б=I_{г.ном}=\frac{235}{\sqrt{3}\cdot 115}\approx 1,2 \text{ kA}.$$

The replacement schemes of all sequences are given in Fig. 6-10b-d.

We lead all resisting to base line ones let us agree.

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Resisting of backward sequence of turbogenerator we take as equal to x''_d; then $x_{11}=x_{21}=0.18$.

For transformers with the connection of windings Y_0/Δ

$$x_{12}=x_{22}=x_{02}=0,105\frac{235}{240}\approx 0,1.$$

Resulting resisting of separate sequences:

$$x_{1\,рез}=x_{2\,рез}=x_{11}+x_{12}=0,18+0,1=0,28;$$

$$x_{0\,рез}=x_{02}=0,1.$$

Ultratransitory currents in the place of short circuit we determine from formula (6-100), accepting for a turbogenerator coefficient of k=1.

Three-phase short circuit:

$$x^{(3)}_{*\,расч}=x_{1\,рез}=0,28;\ m^{(3)}=1$$

and

$$I''^{(3)} = \frac{1,2}{0,28} \approx 4,3 \text{ ka}^{(1)}.$$

Key: (1). kA.

Two-phase short circuit:

$$x^{(2)}_{\text{расч}} = x_{1\,\text{рез}} + x_{2\,\text{рез}} = 2 \cdot 0,28 = 0,56; \; m^{(2)} = \sqrt{3}$$

and

$$I''^{(2)} = \frac{\sqrt{3} \cdot 1,2}{0,56} \approx 3,7 \text{ ka}^{(1)}.$$

Key: (1). kA.

Single-phase short circuit:

$$x^{(1)}_{\text{расч}} = x_{1\,\text{рез}} + x_{2\,\text{рез}} + x_{0\,\text{рез}} = = 2 \cdot 0,28 + 0,1 = 0,66; \; m^{(1)} = 3$$

and

$$I''^{(1)} = \frac{3 \cdot 1,2}{0,66} \approx 5,5 \text{ ka}^{(1)}.$$

Key: (1). kA.

The same value has a current, flowing into the earth/ground through grounded neutral of the transformer:

$$I_з = 3I_0^{(1)} = 5,5 \text{ ka}^{(1)}.$$

Key: (1). kA.

Two-phase short circuit to the earth:

$$x^{(1,1)}_{\text{расч}} = x_{1\text{рез}} + \frac{x_{2\text{рез}} x_{0\text{рез}}}{x_{2\text{рез}} + x_{0\text{рез}}} = 0,28 + \frac{0,28 \cdot 0,1}{0,28 + 0,1} \approx 0,35;$$

$$m^{(1,1)} = \sqrt{3} \sqrt{1 - \frac{x_{2\text{рез}} x_{0\text{рез}}}{(x_{2\text{рез}} + x_{0\text{рез}})^2}} = \sqrt{3} \sqrt{1 - \frac{0,28 \cdot 0,1}{(0,28 + 0,1)^2}} \approx 1,55$$

and

$$I''^{(1,1)} = \frac{1,55 \cdot 1,2}{0,35} \approx 5,3 \text{ ka}^{(1)}.$$

Key: (1). kA.

The current of null sequence according to formula (6-89) composes

$$I_0^{(1,1)} = I_{K1}^{(1,1)} \frac{x_{2\text{рез}}}{x_{2\text{рез}} + x_{0\text{рез}}} = \frac{1,2}{0,35} \cdot \frac{0,28}{0,28 + 0,1} \approx 2,5 \text{ ka}^{(1)},$$

Key' (1) kA.

and current in grounded neutral of the transformer

$$I_3^{(1,1)} = 3I_0^{(1,1)} = 3 \cdot 2,5 = 7,5 \text{ ka}^{(1)}.$$

Key: (1). kA.

Example of 6-13. To determine ultratransitory current in the place of single-phase short circuit at point K (Fig. 6-45a), current in line L-3, currents in grounded neutrals of transformers, voltage in the place of short circuit and on the collecting mains SSh of substation No 1. To construct vector diagrams of the currents in line

L-3 and voltages in the place of short circuit and on busbars SSh of substation No 1.

The data necessary for calculation, are given in the diagram. For all lines to accept $x_1=x_2=0.4$ Ω/km. For transformers with the connection of windings Y_0/Δ $x_0=x_1=x_2$.

We accept

$$S_6=100 \text{ Mva } \overset{(1)}{\text{и}}\ U_6=115 \overset{(2)}{\text{kv.}}$$

Key: (1). and. (2). kV.

then

$$I_6=\frac{100}{\sqrt{3}\cdot 115}=0.5 \overset{(1)}{\text{ka.}}$$

Key: (1). kA.

Since for generators accept $x_2=x_1$, then for straight/direct and backward sequences the diagram of replacement will be one and the same (Fig. 6-45b).

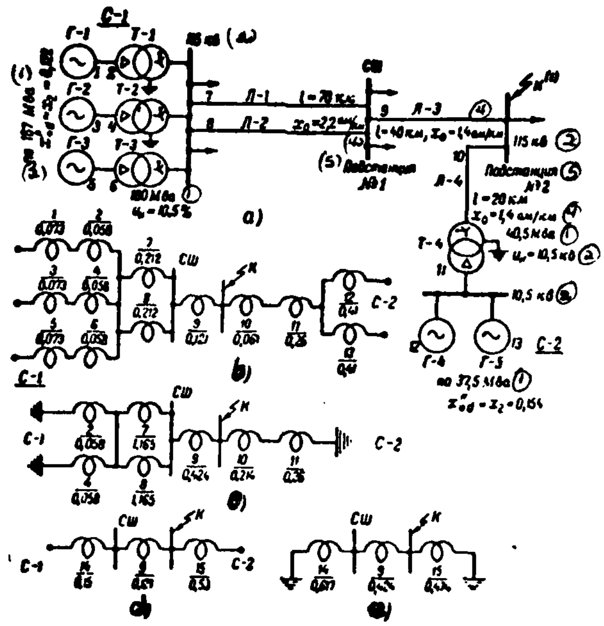

Fig. 6-45. Network and replacement scheme for example of 6-13.

Key: (1). MVA. (2). kV. (3). on. (4). Ω/km. (5). Substation.

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The replacement scheme of null sequence (Fig. 6-45c) is comprised for the case of the grounding of the neutrals of transformers T-1, T-2 and T-4. All resisting of replacement schemes are given to base line power.

By the simplest conversions we obtain the simplified replacement

schemes in Fig. 6-45d and e.

Resulting resisting of the diagrams of separate sequences comprise:

$$x_{1\,рез} = x_{2\,рез} = \frac{(0,15 + 0,121)\,0,53}{0,15 + 0,121 + 0,53} = 0,18;$$

$$x_{0\,рез} = \frac{(0,617 + 0,424)\,0,474}{0,617 + 0,424 + 0,474} = 0,325.$$

Then

$$x^{(1)}_{*рез} = 0,18 + 0,18 + 0,325 = 0,685.$$

Relative value of the current of forward sequence in the place of short circuit according to formula (6-99) (accepting for turbogenerators k=1):

$$I''^{(1)}_{*K1} = \frac{1}{x^{(1)}_{*рез}} = \frac{1}{0,685} = 1,46.$$

In this case

$$I''^{(1)}_{*K2} = I''^{(1)}_{*K0} = I''^{(1)}_{*K1} = 1,46.$$

Absolute value of current in the place of the short circuit:

$$I''^{(1)}_{K} = 3I''^{(1)}_{*K1} I_б = 3 \cdot 1,46 \cdot 0,5 \approx 2,2 \overset{(1)}{ка}.$$

Key: (1). kA.

Symmetrical component voltages in the place short circuits according to formulas (6-88):

$$\dot{U}^{(1)}_{*KA1} = 1,46j\,(0,18 + 0,325) = j0,74,$$

or

$$U^{(1)}_{KA1} = 0,74\,\frac{115}{\sqrt{3}} = 49 \overset{(1)}{кв};$$

$$\dot{U}^{(1)}_{*KA2} = -1,46j0,18 = -j0,26,$$

Key: (1). kV.

or

$$U^{(1)}_{KA2}=0{,}26\,\frac{115}{\sqrt{3}}=17\ \overset{(1)}{\text{кв}};$$

$$\dot{U}^{(1)}_{*KA0}=-1{,}46j0{,}325=-j0{,}48.$$

Key: (1). kV.

or

$$U^{(1)}_{KA0}=0{,}48\,\frac{115}{\sqrt{3}}=32\ \overset{(1)}{\text{кв}}.$$

Key: (1). kV.

Vector diagram of voltages in the place of short circuit is constructed to scale in Fig. 6-46a, according to which if necessary can be determined interphase voltages.

We determine the symmetrical components of current in line L-3;

by the diagram of the straight/direct (reverse) sequence

$$I''^{(1)}_{*1\,\text{Л-3}}=\frac{E_*-U_{*K1}}{x_{14}+x_9}=\frac{1-0{,}74}{0{,}15+0{,}121}\approx 0{,}96,$$

or

$$I''^{(1)}_{1\,\text{Л-3}}=0{,}96\cdot 0{,}5=0{,}48\ \overset{(1)}{\text{ка}}$$

Key: (1). kA.

and

$$I''^{(1)}_{*2\,\text{Л-3}}=I''^{(1)}_{*K2}\,\frac{x_{18}}{x_{14}+x_9+x_{18}}=$$
$$=1{,}46\,\frac{0{,}53}{0{,}15+0{,}121+0{,}53}\approx 0{,}96,$$

or

$$I''^{(1)}_{2\text{к-3}} = 0.48 \overset{(1)}{\text{ка}},$$

Key (1). kA.

i.e. the same value, that also current of forward sequence; this it was to be expected, since for all sources in diagram of forward sequence were accepted emf, equal in magnitude and cophasal, namely $E'' = U_{cp}$ or $E''_{*} = 1$;

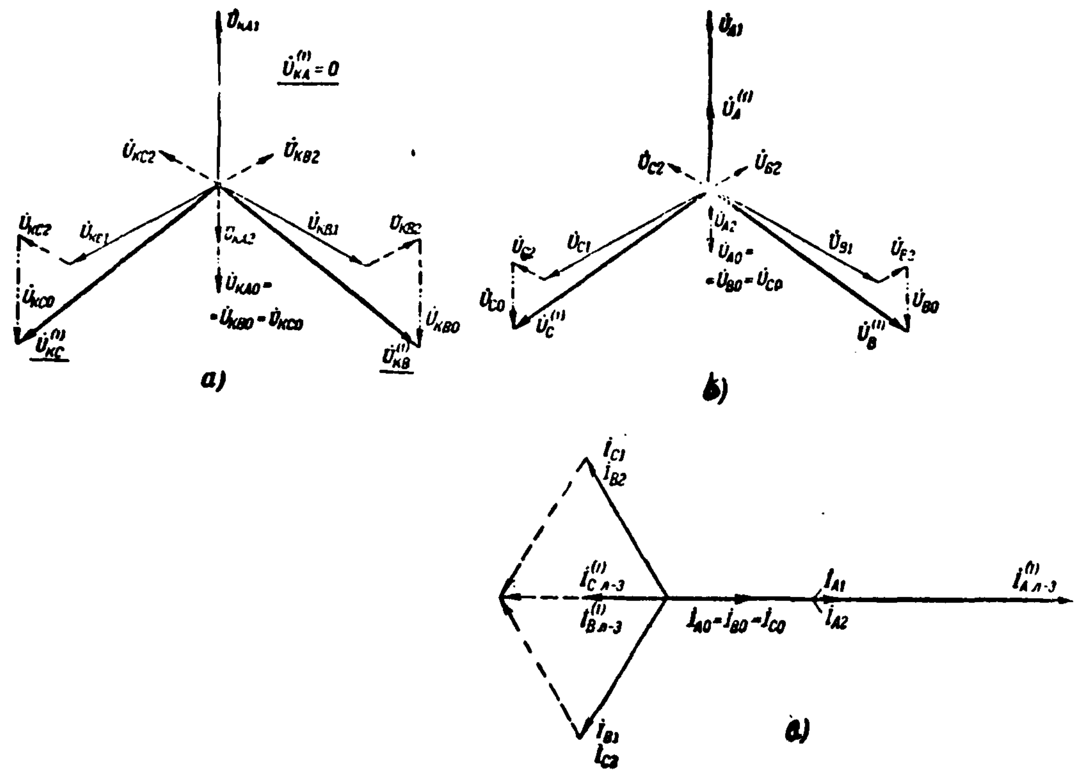

Fig. 6-46. Vector diagrams of voltages and currents for example of 6-13.

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on the diagram of the aull sequence

$$I''^{(1)}_{*0\,Л\text{-}3} = I''^{(1)}_{*K0} \frac{x_{13}}{x_{14} + x_9 + x_{15}} =$$
$$= 1,46 \frac{0,474}{0,617 + 0,424 + 0,474} \approx 0,46$$

or

$$I''^{(1)}_{0Л-3} = 0,46 \cdot 0,5 = 0,23 \text{ ка.}^{(1)}$$

Key: (1). kA.

In Fig. 6-46c is constructed vector diagram of currents and lines L-3, from which are determined the currents in the phases of the line:

$$I''^{(1)}_{AЛ-3} = 1,19 \text{ ка}^{(1)}; \; I''^{(1)}_{BЛ-3} = 0,25 \text{ ка}^{(1)}; \; I''^{(1)}_{CЛ-3} = 0,25 \text{ ка.}^{(1)}$$

Key: (1). kA.

We determine symmetrical component voltages on collecting mains SSh of substation No 1:

$$U^{(1)}_{*A1} = U^{(1)}_{*KA1} + I''^{(1)}_{*1Л-3} jx_* = \\ = j0,74 + 0,96j0,121 = j0,856,$$

either

$$U^{(1)}_{A1} = 0,856 \frac{115}{\sqrt{3}} = 55 \text{ кв}^{(1)};$$

$$U^{(1)}_{*A2} = U^{(1)}_{*KA2} + I''^{(1)}_{*2Л-3} jx_* = \\ = -j0,26 + 0,96j0,121 = -j0,144$$

or

$$U^{(1)}_{A2} = 0,144 \frac{115}{\sqrt{3}} = 9,6 \text{ кв}^{(1)};$$

$$U^{(1)}_{*A0} = U^{(1)}_{*KA0} + I''^{(1)}_{*0Л-3} jx_* = \\ = -j0,48 + 0,46j0,424 = -j0,285,$$

or

$$U^{(1)}_{A0} = 0,285 \frac{115}{\sqrt{3}} = 19 \text{ кв.}^{(1)}$$

Key: (1). kV.

Vector diagram of voltages on busbars SSh is constructed in Fig. 6-46b.

Currents in grounded neutrals of transformers T-1 and T-2 are determined from the calculated above current of null sequence in line L-3:

$$I_{\text{з.Т-1}} = I_{\text{з.Т-2}} = 3\frac{I''^{(1)}_{0Л\text{-}3}}{2} = 3\frac{0,23}{2} \approx 0,35 \text{ ка.}^{(1)}$$

Key: (1). kA.

Neutral current of transformer T-4:

$$I_{\text{з.Т-4}} = 3(I''^{(1)}_{*K0} - I''^{(1)}_{*0Л\text{-}3}) I_б = 3(1,46 - 0,46)\,0,5 = 1,5 \text{ ка.}^{(1)}$$

Key: (1). kA.

Utilizing the given above calculations, it is possible to find currents in the phases of all sections of the diagram as this in question shown on Fig. 6-47. From latter/last diagram it is evident that during single-phase short circuit in network 110 kV in the circuits of generators flow/occur/last the short-circuit currents in two phases. In the feed of the place of single-phase short circuit participates also the aggregate/unit whose transformer works with ungrounded neutral (T-3). Hence it is possible to draw the conclusion

that with a change in the number of grounded neutrals of transformers the value of single-phase short-circuit current in the place of damage changes disproportionately a number of grounded neutrals.

In diagram in Fig. 6-47 all currents are expressed in relative units. Multiplying them to $I_б$, that determined with U_{cp} the appropriate step/stage of voltage, it is easy to determine the absolute value of currents in any phase and in any section of network. Certainly, the determination of current distribution in compound circuits is considerably more difficult.

Example of 6-14. To determine the steady current with three- and two-phase short circuits at point K in the diagram in Fig. 6-48a. There are given all data, necessary for calculation. The turbogenerators of station are equipped with ARV.

We accept $S_б = 3S_{г.ном} = 112{,}5$ MVA and $U_б = U_{cp}$ =10.5 kV, then

$$I_б = I_{г.ном} = \frac{112{,}5}{\sqrt{3}\cdot 10{,}5} = 6{,}2 \text{ kA}^{(1)}.$$

Key: (1). kA.

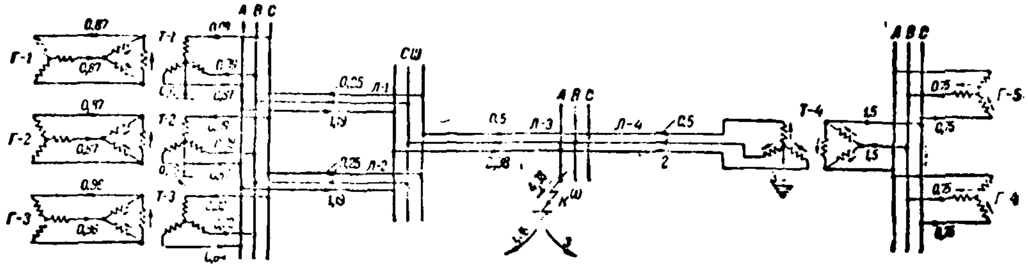

Fig. 6-47. Current distribution (in relative unity) in the network of diagram in Fig. 6-45 during single-phase short circuit at point $K^{(1)}$.

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Fig. 6-48b gives the replacement scheme of the straight/direct (reverse) sequence on which are shown all resisting, led to base line conditions.

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Three-phase short circuit. Replacement scheme for three-phase short circuit takes the form, given in Fig. 6-48c, where

$$x_r = \frac{0,46}{3} = 0,154 \text{ }^{(1)}\text{и } x_c = \frac{0,2}{2} + \frac{0,24}{2} = 0,22.$$

Key: (1). and.

Since short-circuit current from system in time does not change $(S_c = \infty)$, then is determined the steady current from generators and

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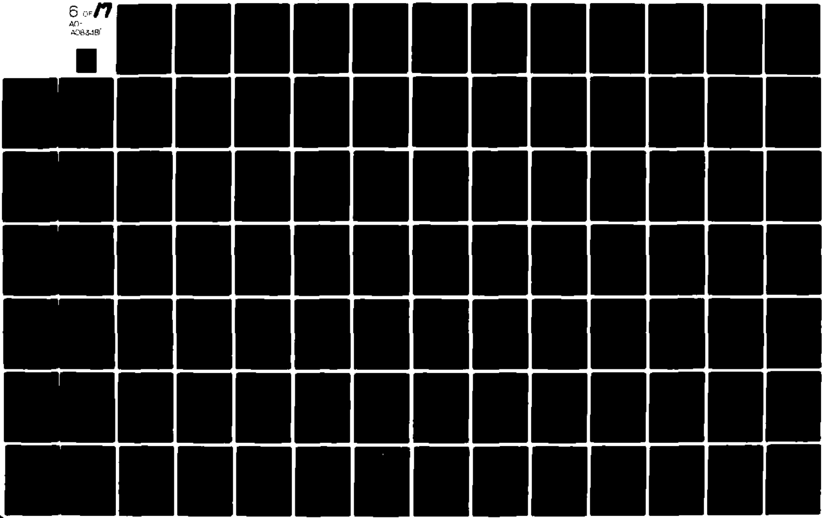

system separately.

For the branch of the generators

$$x^{(3)}_{*расч.г} = x_г = 0{,}154$$

On curve for t=∞ on Fig. 6-25 we find $I^{(3)}_{*\infty г}$ =2.72, then

$$I^{(3)}_{\infty г} = 2{,}72 \cdot 6{,}2 = 17 \ \overset{(1)}{ка.}$$

Key: (1). kA.

For the branch of the system

$$x^{(3)}_{*рез.с} = x_с = 0{,}22;$$

then

$$I^{(3)}_{*\infty с} = I''^{(3)}_{*с} = \frac{1}{0{,}22} = 4{,}55$$

and

$$I^{(3)}_{\infty с} = 4{,}55 \cdot 6{,}2 = 28 \ \overset{(1)}{ка.}$$

Key: (1). kA.

Total steady current of three-phase short circuit at point K:

$$I^{(3)}_{\infty} = I^{(3)}_{\infty г} + I^{(3)}_{\infty с} = 17 + 28 = 45 \ \overset{(1)}{ка.}$$

Key: (1). kA.

Two-phase short circuit. Replacement scheme for this m-ans of damage is given in Fig. 6-48d, where

$$x^{(2)}_{доп} = x_{2рез} = \frac{x_с x_г}{x_с + x_г},$$

since for generators accept $x_2 = x''_d$.

In this case it is necessary to determine resulting resisting $x^{(2)}_{\text{рез.г}}$ and $x^{(2)}_{\text{рез.с}}$ connecting power supplies is direct with the point of short circuit, being guided by the indications, given in §6-9.

Distribution coefficients:

$$C_1 = \frac{x_c}{x_c + x_r} \text{ (1) } C_2 = \frac{x_r}{x_c + x_r}.$$

Key: (1). and.

Resulting resisting of the diagram

$$x^{(2)}_{\text{рез}} = \frac{x_c x_r}{x_c + x_r} + x^{(2)}_{\text{доп}} = 2\frac{x_c x_r}{x_c + x_r}.$$

Resulting resisting of the branches of power supplies:

$$x^{(2)}_{\text{рез.г}} = \frac{x^{(2)}_{\text{рез}}}{C_1} = 2x_r;$$

$$x^{(2)}_{\text{рез.с}} = \frac{x^{(2)}_{\text{рез}}}{C_2} = 2x_r.$$

Thus, when for generators accept $x_2 = x''_d$. it is possible during the computation of two-phase short-circuit currents at the points, analogous to point K on collecting mains, to determine short-circuit current separately from power supplies, accepting doubled resisting of corresponding branches.

Steady current of two-phase short circuit from the generators of

the station

$$x^{(2)}_{*расч.г} = 2 \cdot 0,154 \approx 0,31.$$

On the curve t=∞ on Fig. 6-25 we find

$$I^{(2)}_{*1\infty г} = 2,3;$$

then

$$I^{(2)}_{\infty г} = \sqrt{3} I^{(2)}_{*1\infty г} I_{г.ном} = \sqrt{3} \cdot 2,3 \cdot 6,2 \approx 25 \text{ ка.}^{(1)}$$

Key: (1). kA.

that the more than specific above steady current of three-phase short circuit from generators in 25/17=1.47 time.

Steady current of two-phase short circuit from the system

$$x^{(2)}_{*рез.с} = 2 \cdot 0,22 = 0,44;$$

then

$$I^{(2)}_{*1\infty с} = I''^{(2)}_{*1с} = \frac{1}{x^{(2)}_{*рез.с}} = \frac{1}{0,44} = 2,27$$

and

$$I^{(2)}_{\infty с} = \sqrt{3} I^{(2)}_{*1\infty с} I_б = \sqrt{3} \cdot 2,27 \cdot 6,2 \approx 24 \text{ ка.}^{(1)}$$

Key: (1). kA.

Still simpler this current is determined from to known current $I^{(3)}_{\infty с} = I''^{(3)}_{с}$:

$$I^{(2)}_{\infty с} = I''^{(2)}_{с} = \frac{\sqrt{3}}{2} I''^{(3)}_{с} = \frac{\sqrt{3}}{2} 28 \approx 24 \text{ ка.}^{(1)}$$

Key: (1). kA.

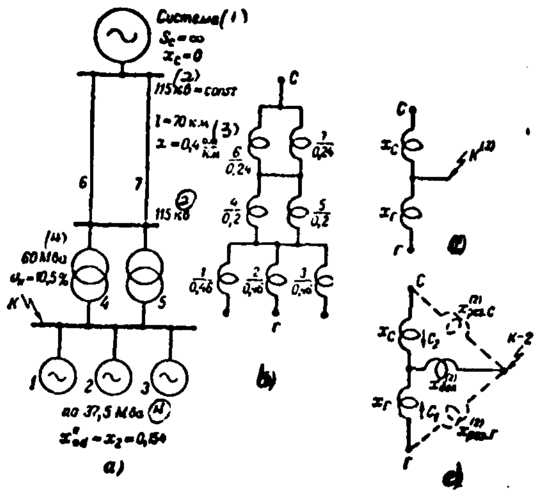

Fig. 6-48. Network and replacement scheme for example of 6-14.

Key: (1). System. (2). kV. (3). Ω/km. (4). MVA.

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Total steady current of two-phase short circuit at point K:

$$I_{\infty}^{(2)} = I_{\infty r}^{(2)} + I_{\infty c}^{(2)} = 25 + 24 = 49 \text{ ka.}$$

Key: (1). kA.

i.e. insignificantly it differs from the specific above three-phase steady current.

On the basis of a latter/last example it is possible to draw the

conclusion that on the power plants, connected with powerful/thick power systems, the two-phase steady current in generator voltage usually little differs from the three-phase steady current and the less, the greater the share of the current of short from system. In the networks of the increased and low voltages, i.e., electrically distant from generators, usually the currents of three-phase short circuits are more than the currents of two-phase closings/shortings. Therefore in the majority of the cases of practice definite when selecting of electrical equipment are the currents of three-phase short circuit.

Chapter Seven.

ACTIONS OF SHORT-CIRCUIT CURRENTS.

7-1. The electrodynamic effects of short-circuit currents.

The electrodynamic force of interaction between two parallel conductors (Fig. 7-1) of arbitrary section, by streamlined with currents i_1 and i_2, determines from the formula:

$$F = 2{,}04\,k_\Phi i_1 i_2 \frac{l}{a} 10^{-8} [\overset{(1)}{kG}]. \qquad (7\text{-}1)$$

Key: (1). kgf.

where i_1 and i_2 - instantaneous values of currents in conductors, a;

l- length of parallel conductors, cm;

a - distance between centers of conductors, cm;

k_Φ - factor of the form (see below).

The force of interaction of two parallel conductors evenly distributed along the length of conductors. In practical calculations this evenly distributed force they replace by net force of F, applied

to conductors in the middle of their length.

In identical direction of flow in conductors they are attracted/tightened, while in different directions - they are repulsed.

Factor of form k_{Φ} depends on the form of the section of conductors and their mutual location. For circular and tubular conductors $k_{\Phi}=1$; for the conductors of other forms of section it is possible to accept $k_{\Phi}=1$ when the section of conductors is small, and their length is great in comparison with the distance between them and it is possible to assume that entire current is concentrated in the axis of conductors. So, with sufficient for purposes practice accuracy accept $k_{\Phi}=1$ during the determination of the forces of interaction between the phases of the busbar/tire constructions/designs of the distributors (see Chapter 10) independent of the form of the section of busbars, since the distances between the busbars of different phases in distributors are sufficiently great and compose several hundred millimeters and more.

But if the distance between the conductors (busbars) of rectangular, box and other sections is small, then $k_{\Phi}\neq 1$. A characteristic example is busbar/tire construction/design to large operating currents, when each phase is comprised from several

rectangular busbars, for example of two busbars 1 (Fig. 7-3), with the small distance between them, equal to the thickness of separators 2, fastened/strengthened to stand-off insulators 3 (attachment of busbars on insulators is not shown).

Fig. 7-2 gives the curves, which make it possible to determine form factor for the busbars of rectangular cross sections [6-1].

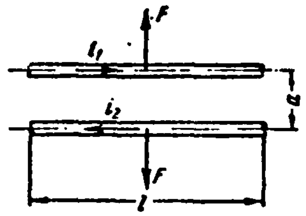

Fig. 7-1. Interaction of two conductors.

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Curves give the dependence of coefficient k_Φ on the relations $\frac{a-b}{b+h}$ (1) и $m=\frac{b}{h}$,

Key: (1). and.

where a - distance between centers of the busbars;

b - width of the busbar;

h - height of tire.

From curves it is evident that $\frac{a-b}{b+h} \geqslant 2$ coefficient $k_\Phi \approx 1$. In other words, if the clearance between busbars (a-b) more than the perimeter of busbar [2(b+h)], then it is possible to accept $k_\Phi = 1$.

The greatest force of interaction between parallel conductors

with the current of two-phase short circuit comprises:

$$F^{(2)}=2{,}04k_{\Phi}i_y^{(2)^2}\frac{l}{a}10^{-8}\ [\overset{(1)}{\kappa\Gamma}]. \qquad (7\text{-}2)$$

Key: (1). kgf.

With current of three-phase short circuit and bussing arrangement of the conductors of three phases in one plane (usual location of busbars in distributors) under severe conditions is located the average/mean phase, to which operates the force

$$F^{(3)}=2{,}04\frac{\sqrt{3}}{2}k_{\Phi}\,i_y^{(3)^2}\frac{l}{a}10^{-8}\ [\overset{(1)}{\kappa\Gamma}],$$

Key: (1). kgf.

or

$$F^{(3)}=1{,}76\,k_{\Phi}i_y^{(3)^2}\frac{l}{a}\,10^{-8}\ [\overset{(1)}{\kappa\Gamma}]. \qquad (7\text{-}3)$$

Key: (1). kgf.

Coefficient $\frac{\sqrt{3}}{2}\approx 0{,}87$ calculates noncoincidence on the basis of the phase of currents in the phases (see §6-5, Fig. 6-15).

If one considers that $\frac{i_y^{(3)}}{i_y^{(2)}}=\frac{2}{\sqrt{3}}$ (see §6-12), then the relationship/ratio between efforts/forces during the three- and two-phase short circuit:

$$\frac{F^{(3)}}{F^{(2)}}=\frac{2}{\sqrt{3}}\approx 1{,}15.$$

Hence it follows that great value the electrodynamic efforts/forces have during the three-phase short circuit, which is in

this respect most dangerous.

Subsequently force $F^{(3)}$ will be determined for the mechanical calculation of the busbars (see Chapter 10) and checking to the mechanical strength of supporting and wall entrance insulators (chapter 9) and some types of current transformers (chapter 21).

Example of 7-1. To determine the force of interaction between the busbars of different phases in distributor, if $i_y^{(3)}=45$ kA, distance between centers of the busbars of adjacent phases a=35 cm and length of busbars is l=2.5 m. Busbars rectangular by the size/dimension 50x6 of mm.

In this case the clearance between busbars (350-6=344 mm) considerably more than the perimeter of busbar [2(50+6) =112 mm], in consequence of which the form factor can be taken as equal to unity ($k_\Phi=1$).

According to formula (7-3)

$$F^{(3)}=1{,}76\cdot 45^2\frac{250}{35}\cdot 10^{-2}=254 \overset{(1)}{\kappa\Gamma}.$$

Key: (1). kgf.

Example of 7-2. To determine the force of interaction between the rectangular busbars of one phase, shown in Fig. 7-3. Impact current $i_y^{(3)}=80$ kA.

In this case the form factor must be taken into consideration.

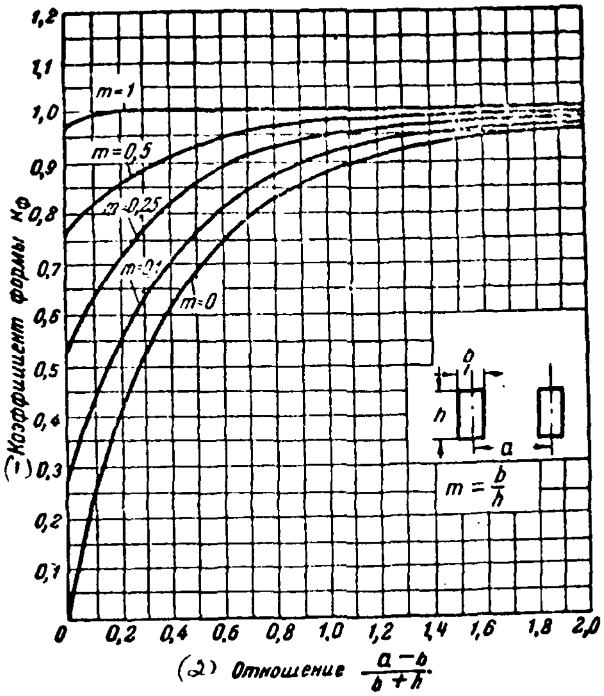

Fig. 7-2. Curves for determining the factor of the form of the busbars of rectangular cross section.

Key: (1). Form factor. (2). Relation.

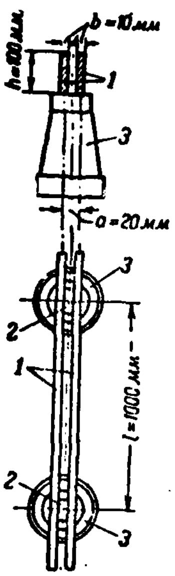

Fig. 7-3. Outlines for example of 7-2.

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We determine relationships/ratios $\frac{a-b}{b+h}=\frac{20-10}{10+100}\approx 0,1$ and $m=\frac{b}{h}=\frac{10}{100}=0,1$. On the appropriate curve (m=0.1) on Fig. 7-2 we find $k_{\phi}=0,44$.

For determining the force of interaction between the busbars of one phase it is necessary to use formula (7-1), assuming/setting in it

$$i_1=i_2=\frac{i_y^{(3)}}{2}=\frac{80}{2}=40 \text{ (1)}$$

Key: (1). kA.

(current of phase it flows/occurs/lasts over two parallel busbars):

then

$$F = 2{,}04 \cdot 0{,}44 \cdot 40^2 \frac{100}{2} \cdot 10^{-2} = 720 \text{ (1)}.$$

Key: (1). kgf.

7-2. Thermal actions of short-circuit currents.

For each element of the electrical installation standards establish a certain heating temperature above which it must not be heated under the given working conditions.

In this case are distinguished two fundamental modes/conditions: the prolonged normal mode of work and the short-term mode/conditions of short circuit.

The temperature of heating conductor in the normal mode of work $\vartheta_н$ is defined as the sum of the ambient temperature ϑ_0 and temperature of overheating $\tau_н$ conductor with respect to ambient temperature, i.e., $\vartheta_н = \vartheta_0 + \tau_н$. The temperature of overheating $\tau_н$ is determined from the condition that a quantity of heat, isolated in conductor, is equal to the quantity of heat, diverted from it for the same time into the environment.

The reliable work of current-carrying part in normal mode can be provided only when $\vartheta_н \leq \vartheta_{доп}$, where $\vartheta_{доп}$ - maximum long permissible temperature of heating the current carrying part, which occurs with

the course on it of the long let-go current of load $I_{доп}$ (or rated current $I_{ном}$) and at a calculated ambient temperature (see §3-3). Heating conductors in normal mode is examined in course "Electrical networks and electric power lines" [7-1]; therefore we will be restricted below only to the examination of heating conductors during short circuits.

With the short-term course of short-circuit current the temperature of heating conductor $\vartheta_к$ does not succeed in reaching the steady value and is defined as the sum of the temperature of conductor to short circuit $\vartheta_н$ and temperature of overheating by its short-circuit current $\tau_к$, i.e. $\vartheta_к = \vartheta_н + \tau_к = \vartheta_0 + \tau_н + \tau_к$. In the heaviest case under the temperature of conductor to short circuit should be understood its steady temperature at nominal load, i.e., $\vartheta_н = \vartheta_{доп}$.

The time of the course of short-circuit current is very small and usually it does not exceed several seconds or even fractions of a second, which makes it possible not to consider the removal of the heat (heat emission) into the environment for the time of short circuit and to consider that entire heat, isolated in conductor for the time of short circuit, proceeds with an increase in its temperature (adiabatic process of heating).

Fig. 7-4 shows a change in the temperature of conductor with the

course on it of short-circuit current. To short circuit the conductor had temperature $\vartheta_н$. Short circuit occurred at moment/torque t_1, after which the temperature of conductor rapidly increased, after achieving value $\vartheta_к$ at moment/torque t_2, then faulted circuit was disconnected by the appropriate switch.

After the cutoff/disconnection of circuit the conductor gradually is cooled to ambient temperature ϑ_0. if we examine the conductor of off circuit (Fig. 7-4), or to certain temperature $\vartheta_н'$ of the determined by the new value of the current of load circuit after the cutoff/disconnection of short circuit.

The maximum temperature of conductor during short circuit $\vartheta_к$ is very short-term (peak of temperature), which makes it possible to allow/assume during short circuit heating conductors, considerably larger than in normal mode.

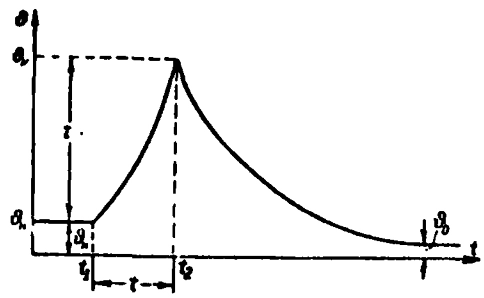

Fig. 7-4. Change in the temperature of conductor during heating by its short-circuit current.

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The maximum permissible heating of current-carrying parts by short-circuit current is determined by the thermal properties of their insulation and by the conditions of retaining/preserving/maintaining the mechanical strength of the metal of conductor. The latter is explained by the fact that during heating to the specific temperature with the subsequent slow cooling occurs the annealing of metal, as a result of which sharply descends its mechanical strength.

The "Rules of the device/equipment of electrical devices" [3-6] established/installed maximally permissible short-term temperature excesses of heating conductors by short-circuit currents

when to the moment/torque of short circuit the temperature of conductor does not exceed the long permissible temperature. Based on this, usually accept the following maximally permissible short-term temperatures of heating conductors during the short circuits:

bare copper busbars:..., $\vartheta_{к\ макс} = 300°C$

Bare aluminum busbars:... $\vartheta_{к.\ макс} = 200°C$

Bare steel busbars:

a) upon direct connection to the terminals/grippers of apparatuses:..., $\vartheta_{к.\ макс} = 300°C$

b) in the absence of connections to the terminals/grippers of apparatuses:..., $\vartheta_{к.\ макс} = 400°C$

Power cables with copper veins/strands and paper insulation to 10 kV inclusively:..., $\vartheta_{к.\ макс} = 250°C$

Then, but with aluminum veins/strands:... $\vartheta_{к.\ макс} = 200°C$

Power cables with paper insulation on 20 and 35 kV:... $\vartheta_{к.\ макс} = 175°C$

Power india-rubber cables and wire with rubber and polychlorovinyl insulation:. . . $\vartheta_{к.\,макс} = 200°\,C$

The problem of testing the current-carrying part (wire, busbar, cable) to thermal resistance is reduced to the determination of the greatest heating temperature by short-circuit current $\vartheta_к$ and its comparison with maximally permissible temperature $\vartheta_{к.макс}$. The current-carrying part thermally stable, if is observed the condition:

$$\vartheta_к < \vartheta_{к.макс}.$$

For this, first of all, necessary to know the duration of the short circuit t (the estimated time of the action of short-circuit current, Fig. 7-4) which is composed from the time of action of relaying $t_{защ}$, of that established/installed in the nearest to place damage of switch, and the tripping time of this switch $t_в$:

$$t = t_{защ} + t_в. \qquad (7\text{-}4)$$

The tripping time of switch with drive is determined by time interval from the closing a circuit of the disconnecting electromagnet of the drive of switch to full/total/complete arc extinction between the contacts of switch, which appears with the cutoff/disconnection of current. In the absence of the data of manufacturing plant it is possible to accept:

for low-speed switches $t_в = 0.2$ s;

for quick-break switches $t_s = 0.1$ s.

If in the nearest to place damage of switch are established/installed several relayings, then during testing of current-carrying part to thermal resistance one should proceed from the time of action of the fundamental protection, which operates during the short circuit in question. If protection has the dead zone (see Vol. 2), then during short circuit in this zone should be considered the time of that protection, that works during short circuit in dead zone. Respectively is taken current during short circuit in this zone.

The quantity of heat, isolated with short-circuit current for time t, will be determined according to the law of a Lentz-joule:

$$Q_{\kappa} = \int_0^t 0.24\, I_{\kappa t}^2 r\, dt, \qquad (7\text{-}5)$$

where $I_{\kappa t}$ - the effective value of short-circuit current;

r - resisting of conductor.

Analytical determination Q_{κ} from this formula is very difficult as a result of the complexity of the law of change in the time of short-circuit current, which consists of two component/term, especially when, on the generators, automatic field regulators are

present. Therefore in practice apply the set-forth below short-cut method determinations $Q_к$, based on the following. They consider that the conductor is heated not by the real changing in time short-circuit current, but by the constant/invariable in value current, equal to the steady value of short-circuit current. Respectively instead of the real time t the courses of short-circuit current accept certain estimated time $t_ф$, called fictitious time.

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If, furthermore, for simplification in the conclusion/output to consider that resisting of conductor remains constant and equal to certain average/mean value $r_{ср}$ for the possible range of temperature of heating, then formula (7-5) will be converted into the usual elementary expression of the law of a Lentz-joule:

$$Q_к = 0{,}24 I^2_\infty r_{ср} t_ф. \qquad (7\text{-}6)$$

Fictitious time $t_ф$ of action of short-circuit current is the time during which the steady current separates/liberates the same quantity of heat, as the real changing in time short-circuit current for real time.

Let us explain the concept of fictitious time by graphic construction in Fig. 7-5. Area 0 abc, limited coordinate axes and curved $I^2_{кt} r_{ср} = f(t)$ for time t, on certain scale is equal to a quantity

of heat $Q_к$. If we draw the parallel to the axis of abscissas straight line, which corresponds to the value of the steady current, then, obviously, the task of determining the fictitious time will come to the determination of the abscissa of rectangle with ordinate $I^2_{\infty}r_{cp}$, area of which is equivalent the area, enclosed by curve for time t. Area Q_1 is general/common/total for the areas, formed by quadratic curve and they are equivalent rectangles, while area $Q_4=Q_2+Q_3$; therefore

$$Q_к=Q_1+Q_2+Q_3=Q_1+Q_4=0{,}24I^2_{\infty}r_{cp}t_{ф}.$$

For the time of the course of short-circuit current the temperature of overheating conductor comprises $\tau_к$, therefore the quantity of heat, absorbed in conductor for the time of short circuit, can be determined by the formula:

$$Q_{погл}=sl\gamma c_1\tau_к, \qquad (7\text{-}7)$$

where s - a section of conductor, mm²;

l - length of conductor, m;

γ - material density of conductor, g/cm³;

c_1 - specific heat, cal/g·°C.

Since the process of heating conductor by short-circuit current is considered as process adiabatic ($Q_к=Q_{погл}$), that, equalizing the

right sides of formulas (7-6) and (7-7), expressing specific heat through C= $\gamma c_1/0.24$ [W•s/cm³•°C] and $r_{cp}=\rho_{cp}\frac{l}{s}$, where ρ_{cp} - average/mean resistivity of conductor for the temperature range in question, after conversion we obtain:

$$\tau_{\kappa}=\frac{\rho_{cp}}{C}\left(\frac{I_{\infty}}{s}\right)^{2}t_{\phi}. \qquad (7\text{-}8)$$

Stagnation temperature of heating conductor during short circuit comprises:

$$\vartheta_{\kappa}=\vartheta_{\text{н}}+\tau_{\kappa}=\vartheta_{\text{н}}+\frac{\rho_{cp}}{C}\left(\frac{I_{\infty}}{s}\right)^{2}t_{\phi}. \qquad (7\text{-}9)$$

On the basis of formula (7-9), it is possible to give following determination t_{ϕ}: the fictitious time of action of short-circuit current is the time during which the steady current heats current-carrying part to the same temperature, to which it would be heated by the changing in time short-circuit current within the real (calculation) time t.

Short-circuit current consists of periodic and aperiodic component/term, with respect to what they accept:

$$t_{\phi}=t_{\phi.\text{п}}+t_{\phi.\text{а}}, \qquad (7\text{-}10)$$

where $t_{\phi.\text{п}}$ - fictitious time of action of periodic of component/term of short-circuit current;

$t_{\phi.\text{а}}$ - the same of aperiodic of component/term.

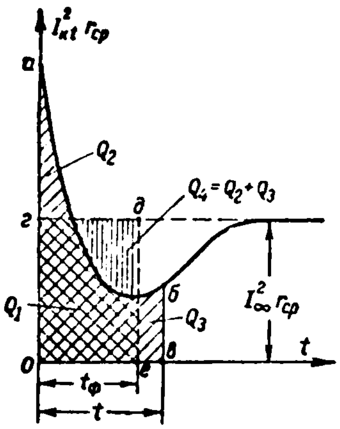

Fig. 7-5. Graphic determination of the fictitious time of action of **short-circuit current with generator with automatic field** regulator.

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The fictitious time of periodic of component/term $t_{\phi.n}$ is the time **during which the steady current separates/liberates in** conductor the **same quantity of heat, as periodic component/term** for real time.

The value of the fictitious time of periodic of component/term **determines by curves in Fig. 7-6, which gives** fictitious time $t_{\phi.\Pi}$ **depending on real time and ratio of the effective** value of initial **ultratransitory short-circuit current to the steady** current $\beta'' = \frac{I''}{I_\infty}$, **i.e.**

$$t_{\phi.n} = f(\beta'', t).$$

Let us note that with absence on the generators of automatic field regulators relation $\beta''=\frac{I''}{I_\infty}$ is more than unity and $t_{\Phi.n}>t$. During short circuit at the distant point β''=1 and

$$t_{\Phi.n}=t=t_{\text{зам}}+t_{\text{в}}.$$

If on generators are automatic field regulators, then relation β'' can be more or less than unity, and it can be equal to unity also with the nondistant/unremoved point of short circuit (see curves in Fig. 6-21). Therefore also the fictitious time of periodic of component/term can be more or less than the real time of the course of short-circuit current ($t_{\Phi.n}\lessgtr t$) and it is equal to real time only during short circuit at the distant point. In other words, if as a result of the calculation of short-circuit current it proves to be that I''=I_∞, but all intermediate values are less (curve 4 in Fig. 6-21), then $t_{\Phi.n}<t$ and it must be determined by curves in Fig. 7-6 with β''=1. But if it proves to be that $I''=I_{nt}=I_\infty$ (straight line 6 in Fig. 6-21), then $t_{\Phi.n}=t$.

Curves in Fig. 7-6 are applied for determination $t^{(2)}_{\Phi.n}$ and during the two-phase short circuit; in this case

$$\beta''^{(2)}=\frac{I''^{(2)}}{I^{(2)}_\infty}=\frac{0{,}87I''^{(3)}}{I^{(2)}_\infty}.$$

The fictitious time of aperiodic of component/term $t_{\Phi.a}$ is the time during which the steady current separates/liberates in conductor the same quantity of heat, as aperiodic component/term for real time.

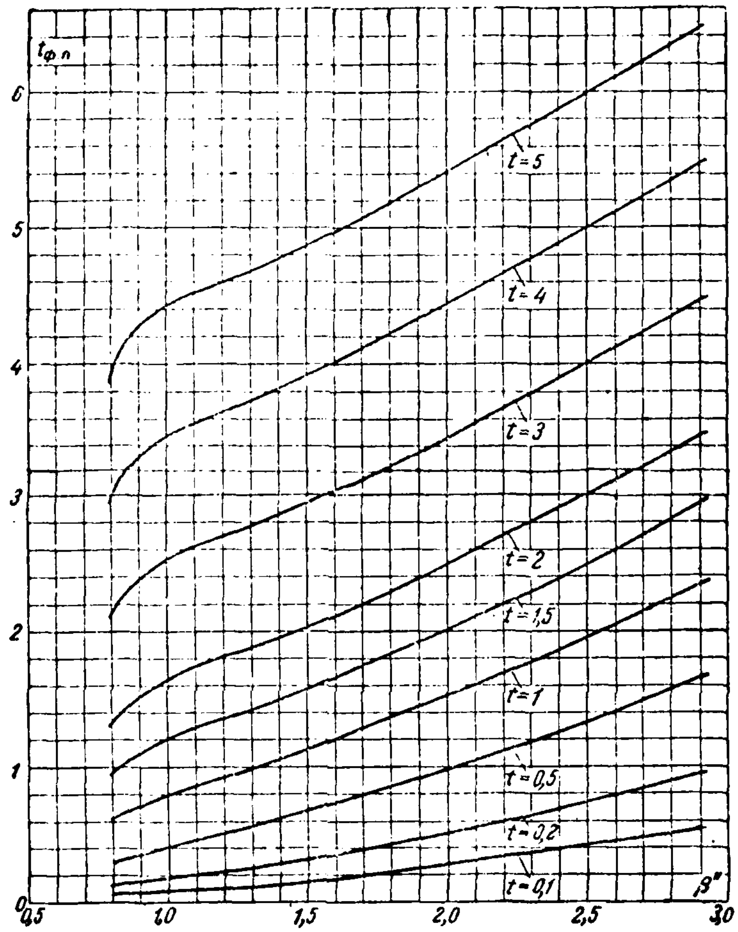

Fig. 7-6. Curves of the fictitious time of periodic of component/term of short-circuit current taking into account automatic field regulators.

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The value of the fictitious time of aperiodic of component/term can be determined from the formula (conclusion/output see [7-2])

$$t_{\Phi.a} = T_a \beta''^2 \left(1 - e^{-\frac{t}{0.5T_a}}\right). \qquad (7\text{-}11)$$

For branch circuits are above 1000V on the average it is possible to accept $T_a = 0.05$ s, then with t>0.1 s approximately $e^{-\frac{t}{0.5T_a}} \approx 0$ and

$$t_{\Phi.a} = 0.05\beta''^2. \qquad (7\text{-}12)$$

Aperiodic component/term attenuates very rapidly (during 0.2-0.1 s); therefore during the determination of the temperature of heating conductor by short-circuit current of its one should consider only with estimated time t<1 s, since only in this case the isolated by it quantity of heat is commensurated with the quantity of heat, isolated by periodic by component/term.

Formulas (7-8) and (7-9) are brought out under the assumption of the constancy of the resistivity of conductor in the process of heating by its short-circuit current. In actuality ρ can considerably change; therefore calculation $\tau_к$ or $\vartheta_к$ according to these formulas can lead to errors.

Therefore in practice designs the temperature of heating conductor by short-circuit current usually determine by curves [1] in

Fig. 7-7, which gives dependence $\theta_{\kappa}=f(j^2t)$ taking into account change ρ and C during heating of conductor and without taking into account heat emission into the environment.

FOOTNOTE [1]. Curves are constructed lower by S. A. Gelikoiskiy. ENDFOOTNOTE.

Here j=I/s - current density in conductor. Curves are constructed for the initial temperature of conductor, equal to zero.

For the purpose of simplification in the recordings let us agree the values of abscissa to designate by letter $A=j^2t=(I/s)^2t$.

Order of the use of curves following (Fig. 7-8). First by the temperature of conductor to short circuit $\theta_{н}$ is determined by appropriate curve the value of abscissa $A_{н}$ (point a in heating curve it is the initial point of heating conductor by short-circuit current).

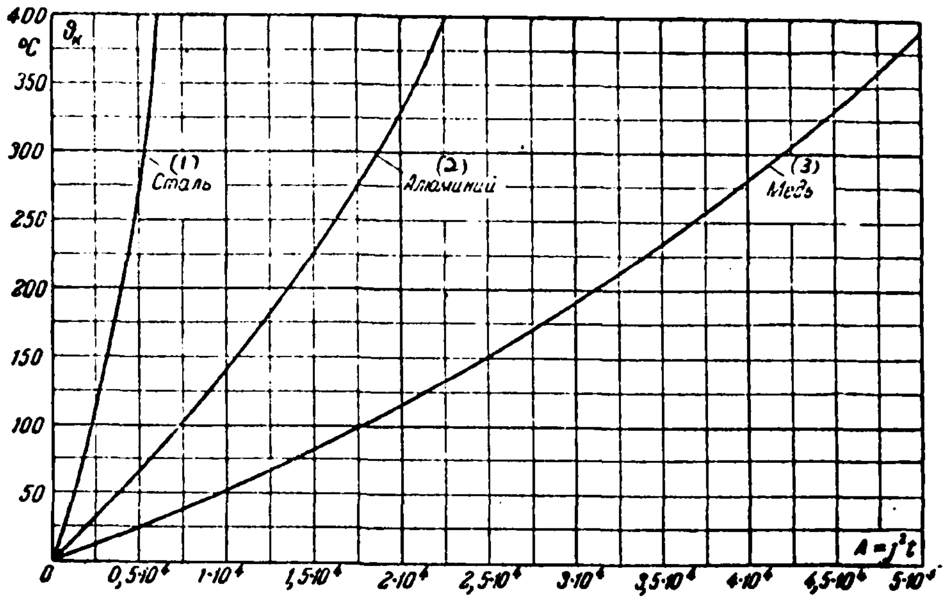

Fig. 7-7. Curves for determining the temperature of heating current-carrying parts during short circuit.

Key: (1). Steel. (2). Aluminum. (3). Copper.

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Then is determined the value of the abscissa, which corresponds to the temperature of heating conductor by short-circuit current:

$$A_к = A_н + \left(\frac{I_\infty}{s}\right)^2 t_ф, \qquad (7\text{-}13)$$

and on it - temperature of conductor $\vartheta_к$.

From §6-12 it is known that during short circuit at any point of network $I''^{(3)}>I''^{(2)}$. Therefore, if as a result of the calculation of short-circuit current it turned out that $I_{\infty}^{(3)}>I_{\infty}^{(2)}$, the and heating effects should be determined during three-phase short circuit. But if it turned out that $I_{\infty}^{(2)}>I_{\infty}^{(3)}$, then heating effects can be more either with three-phase or during two-phase short circuit, which depends on the duration of the course of current. Since $Q\equiv I_{\infty}^{2}t_{\phi}$, that for solving this question is sufficient to compare values $I_{\infty}^{2}t_{\phi}$ for both means of short circuit.

If $I_{\infty}^{(3)2}t_{\phi}^{(3)}>I_{\infty}^{(2)2}t_{\phi}^{(2)}$, then heating effects are more with three-phase short-circuit current, and vice versa. Let us recall, as noted into §6-12 that when $x_{*\text{расч}}>0{,}6$ always $I_{\infty}^{(3)}>I_{\infty}^{(2)}$. Therefore during short circuit on the side of the secondary voltage of substations, in networks after linear reactors and in installations of their own needs of stations heating effects are always more with three-phase short-circuit current.

If calculation shows that with the accepted on the normal mode of work section of current-carrying part the temperature of its heating during short circuit is obtained inadmissibly large $(\vartheta_{\kappa}>\vartheta_{\kappa.\text{макс}})$, then it is expedient for the purpose of the acceleration of calculations to determine the minimum permissible section of current-carrying part by the heating condition by its short-circuit

current. For this through the known temperature of the normal mode of current-carrying part $\theta_н$ and maximum permissible for it temperature $\theta_{к.макс}$ find through the appropriate curve on Fig. 7-7 values of abscissa $A_н$ and $A_{к.макс}$, and then, using formula (7-13), is determined the minimum permissible section of the current-carrying part:

$$s_{мин} = I_\infty \sqrt{\frac{t_ф}{A_{к.макс} - A_н}}. \qquad (7\text{-}14)$$

Let us designate $\sqrt{A_{к.макс} - A_н} = C$, then

$$s_{мин} = \frac{I_\infty}{C} \sqrt{t_ф}. \qquad (7\text{-}15)$$

For the majority of practical calculations it is possible to take the following values of C:

for copper busbars and cables with copper veins/strands to 10 kV inclusively ... C=165

for aluminum busbars and cables with aluminum veins/strands to 10 kV inclusively ... C=90

for steel busbars with:... $\theta_{к.макс} = 400°$ C $C = 70$

for steel busbars with .... $\theta_{к.макс} = 300°$ C $C = 60$

On $s_{мин}$ is selected the near larger standard section of the conductor (on appropriate reference tables to cables, busbars and the

like - see applications/appendices).

If the current of load selected thus current-carrying part considerably the less long let-go current according to norms, then is expedient the refinement of calculation by determining the real temperature of current-carrying part to short circuit according to the formula:

$$\vartheta_{н}=\vartheta_{0}+(\vartheta_{доп}-\vartheta_{0})\left(\frac{I_{н}}{I_{доп}}\right)^{2}. \qquad (7\text{-}16)$$

where $I_{н}$ - current of the load of the current-carrying part;

$\vartheta_{н}$ - temperature of heating current-carrying part with the current of load $I_{н}$;

$I_{доп}$ and $\vartheta_{доп}$ - long let-go current and temperature of current-carrying part with normal operation (according to tabulated data);

ϑ_{0} - Calculated ambient temperature.

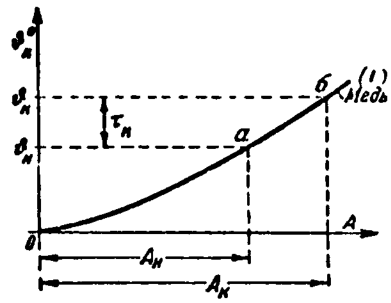

Fig. 7-8. Determination of temperature $\vartheta_к$ taking into account temperature $\vartheta_н$ of current-carrying part to short circuit.

Key: (1). Copper.

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The refinement of the value of temperature $\vartheta_н$ frequently makes it possible to select the near substandard range section of current-carrying part in comparison with $s_{мин}$ (with necessary checkout determination $\vartheta_к$).

If the current-carrying parts, selected on the currents of the normal mode of work, excessively overheat by short-circuit current, then should be thought over the possibility of the artificial limitation of the value of the short-circuit current and decrease of the time of its action (decrease of the operating time of relaying).

It is necessary to remember that an increase in the section of current-carrying parts in the conditions of acting the short-circuit currents is always less desirably as a result of the overexpenditure of nonferrous metal.

Against the actions of short-circuit currents are not checked [3-6]:

1) the current-carrying parts, shielded by the safety fuses (see Chapter 14) or high-impedance current-limiting resisting (for example, busbar in the circuits of voltage transformers);

2) busbar and cables to individual receivers and separate small distribution points of noncritical designation/purpose under the condition of such separator of these current-carrying parts with which their damage during short circuits does not lead to blast or fire or to the damage of the adjacent current-carrying parts and equipment; it must be also provided the possibility of replacing the conductor without the considerable difficulties;

3) busbar and cables to critical individual receivers, including to shop transformers in total power to 750 kVA inclusively and with primary voltage to 10 kV inclusively, if in electrical or technological part is a necessary redundancy with which the

cutoff/disconnection of the receivers indicated does not cause the disorder of production process (with the observance of the indicated in p. 2 conditions of separator).

Example of 7-3. To check to thermal resistance during short circuit power paper-insulated cable with copper veins/strands by section 3x150 mm² with the following data:

$$\vartheta_н = 60°\,C;\ I''^{(3)} = 25\ ка;\ I_\infty^{(3)} = 12{,}5\ ка;$$
$$I_\infty^{(2)} = 17{,}6\ ка;\ t_{защ} = 0{,}7\ сек.$$

Key: (1). kA. (2). s.

Switches low-speed.

The estimated time of the action of short-circuit current we determine from formula (7-4):

$$t = t_{защ} + t_в = 0{,}7 + 0{,}2 = 0{,}9\ сек.$$

Key: (1). s.

We determine, with what means of short circuit are more thermal actions. Since t<1 s, then calculation we conduct taking into account aperiodic component/term.

Fictitious time during the three-phase short circuit

$$\beta''^{(3)} = \frac{I''^{(3)}}{I_\infty^{(3)}} = \frac{25}{12{,}5} = 2.$$

On curves in Fig. 7-6 with $\beta''=2$ and t=0.9 s we find $t_{\phi.n}=1,4$ s. According to formula (7-12) we determine:

$$t_{\phi.a}=0{,}05\beta''^2=0{,}05\cdot 2^2=0{,}2 \text{ сек.}^{(1)}$$

Key: (1). s.

Full/total/complete fictitious time

$$t_{\phi}^{(3)}=t_{\phi.n}+t_{\phi.a}=1{,}4+0{,}2=1{,}6 \text{ сек.}^{(1)}$$

Key: (1). s.

Fictitious time during the two-phase short circuit

$$I''^{(2)}=0{,}87I''^{(3)}=0{,}87\cdot 25=21{,}8 \text{ ка;}^{(1)}$$

$$\beta''^{(2)}=\frac{I''^{(2)}}{I_{\infty}^{(2)}}=\frac{21{,}8}{17{,}6}=1{,}24.$$

Key: (1). kA.

On curves in Fig. 7-6 with $\beta''=1.24$ and t=0.9 s we find $t_{\phi.n}\approx 0{,}9$ s. According to formula (7-12) we determine:

$$t_{\phi.a}=0{,}05\cdot 1{,}24^2\approx 0{,}08 \text{ сек.}^{(1)}$$

Key: (1). s.

Full/total/complete fictitious time

$$t_{\phi}^{(2)}=0{,}9+0{,}08=0{,}98 \text{ сек.}^{(1)}$$

Key: (1). s.

Comparing the expressions of form $I_{\infty}^2 t_{\phi}$, we find:

$$12{,}5^2\cdot 1{,}6<17{,}6^2\cdot 0{,}98,$$

consequently, in thermal sense is more dangerous two-phase short circuit.

On curve for copper in Fig. 7-7 when $\vartheta_н = 65°$ C we find $A_н = 1{,}1 \cdot 10^4$. Further we determine:

$$A_к = A_н + \left(\frac{I_\infty}{s}\right)^2 t_ф = 1{,}1 \cdot 10^4 + \\ + \left(\frac{17\,600}{150}\right)^2 \cdot 0{,}98 = 2{,}45 \cdot 10^4.$$

On curve for copper we find $\vartheta_к \approx 150°$ C. that less $\vartheta_{к.макс} = 250°$ C (see above), i.e., cable is thermostable.

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Chapter Eight.

LIMITATION OF SHORT-CIRCUIT CURRENTS.

8-1. General information.

In powerful/thick electrical devices and supplied by them electric systems the short-circuit currents can reach such high values, that electrical equipment of electrical stations and substations, and also section of the cables of electric system is necessary to select not according to the conditions of normal mode, but on the basis of the stabilization of their work during short circuits. The use/application of electrical equipment and cables, calculated for large short-circuit currents, leads to a considerable increase in initial costs of electrical devices and their networks/grids. In certain cases the short-circuit currents can be so great that generally proves to be impossible or very difficult the selection of electrical equipment and cables, stable during short

circuits.

Therefore in powerful/thick electrical devices apply artificial measures the limitations of short-circuit currents how is reached the possibility of applying of the cheaper electrical equipment: lighter types of electrical devices, busbars and the cables of smaller sections. Ideal would be such condition when the electrical equipment, selected according to the conditions of normal mode, would prove to be stable and during short circuits.

Are examined below the different methods of limiting the short-circuit currents. The selection of one or the other method of limitation is determined by local mounting conditions and must be reinforced by the technical-economic calculation: compare the fundamental and operating costs of the versions of installation without limitation and with the limitation of short-circuit current or compare the same values for versions with the different methods of limiting the short-circuit current. In this case should be considered not only this installation, but it is compulsory and that electric system which from it is supplied.

From powerful/thick electrical stations and substations are supplied the very branched cable systems with the numerous reducing substations, on they are which established/installed a large number

of different electrical devices. Therefore, if the realization of actions for the limitation of short-circuit currents leads even to certain increase in the capital expenditures and the operating costs for this installation, then this, as a rule, with excess it is redeemed due to the reduction of prices of the cables of network/grid and electrical equipment of substations, and in certain cases and due to the decrease of operating costs on electric system and substations. For example, during the setting up of reactors on the waste/exiting cable lines of power plant (Fig. 8-7c) the cost/value of the construction of the distributor of station usually increases with certain increase in the operating costs (energy loss in reactors, expenditure for the repair of reactors, etc.). At the same time these supplementary consumption usually many times overlap due to the decrease of capital expenditures and operating costs on network/grid and reducing substations.

In general the limitation of short-circuit current is achieved by an increase in the resistor/resistance of short circuit either via the realization of the separate operation of the feeding aggregates/units and lines of electric system or by the inclusion consecutively/serially into the circuit of special resistors/resistances.

It is most considerable the value of short-circuit current can

be restricted, if to refuse from multiple operation on the general/common/total electric system of generators, and especially the power plants of system. However, this is completely inadmissible on the series/row of the technical-economic reasons: to sharp deterioration in the efficiency/cost-effectiveness of the work of separate aggregates/units, stations and power systems as a whole, to a very considerable decrease in the reliability of the power supply of users, an increase of the reserve capacity of aggregates/units, etc., in more detail those presented in Chapter 3 and 22. On the contrary, the clearly expressed trend of contemporary development of power system management in all countries of peace/world is ever wider association of power plants and separate power systems for multiple operation and creation of the high-power pools.

At the same time in practice is used extensively for limiting the value of short-circuit currents the separate work of the step-down transformers and lines of the feeding electric system, about which it will be said below.

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For an artificial increase in the resistor/resistance of short circuit are connected in three phases inductive reactances, called reactors, or effective resistance.

In installations with voltage higher than 1000 V, where relative value of the effective resistance of circuit is usually small, the larger limitation of short-circuit current is achieved by the setting up of reactors. The current-limiting effective resistance are applied mainly in the low-power circuits of voltage transformers (see Chapter 20). Will be examined below limitation of short-circuit currents with the aid of reactors.

When selecting and development of the schematics of the electrical connections of installations and networks/grids it is necessary to consider the possible strength of currents of short closing/shorting and, other conditions being equal, to give preference to those diagrams, in which their value is less (see Vol. 2, Chapter 1-5).

One of such cases is illustrated by diagrams in Fig. 8-1. Let us assume that from the district power plant, equipped by two powerful/thick turbo units, electric power must be transmitted along two electric power lines by voltage 220 kV on the busbars of the substation of power system, which is located from power plant at a distance of 150 km. Are possible two versions of the diagram of power plant as this shown in Fig. 8-1a and c. In the first version at

station are installed the collecting mains by voltage 220 kV, connected with two parallel electric power lines with the busbars of the substation of system.

In the second version are fulfilled block connections generator - the step-up transformer - transmission line without collecting mains 220 kV at station. Block diagram is considerably simpler and cheaper, for its fulfillment is required less than electrical equipment. At the same time in block diagram are considerably less short-circuit currents on power plant, which illustrates the given below example.

Example of 8-1. To compare the strengths of impact currents during three-phase short circuit at points K on diagrams in Fig. 8-1a and c.

The initial data:

Turbogenerators G-1 and G-2: $S_{г.ном} = 235$ MVA; $U_{г.ном} = 15{,}75$ kV; $x''_{d} = 0{,}19$.

Transformers T-1 and T-2: $S_{т.ном} = 240$ MVA; $u_к = 14\%$.

Lines L-1 and L-2: l=150 km; x=0.4 Ω/km.

System C: $S_{c.ном}=3000$ MVA; $x_{*c}=0{,}9$ (to the busbars of the substation of system, referred to the nominal power of system).

Medium voltages: the step/stage of generator voltage 15.75 kV, step/stage of the increased voltage 230 kV.

We accept $S_б=1000$ MVA; we lead to it the resistors/resistances of all network elements we connect of substitution for both versions (Fig. 8-1b and c) with the indication of them of the given relative resistors/resistances.

During determination i_y we separate/liberate G-2 into separate branch, since for it one should accept $k_y=1{,}9$.

For the step/stage of short circuit $U_б=U_{cp}=15{,}75$ kV and

$$I_б=\frac{1000}{\sqrt{3}\cdot 15{,}75}=36{,}7 \text{ kA}.$$

Calculation for the first version (Fig. 8-1a and b).

Resulting resistor/resistance from G-1 and C.

$$\frac{(x_1+x_8)\left(\frac{x_5}{2}+x_7\right)}{x_1+x_8+\frac{x_5}{2}+x_7}+x_6=$$

$$=\frac{(0{,}81+0{,}58)\left(\frac{1{,}13}{2}+0{,}3\right)}{0{,}81+0{,}58+\frac{1{,}13}{2}+0{,}3}+0{,}58=1{,}11,$$

then

$$i_y=1{,}8\sqrt{2}\cdot\frac{36{,}7}{1{,}11}+1{,}9\sqrt{2}\cdot\frac{36{,}7}{0{,}81}=206 \text{ kA}.$$

Calculation for the second version (Fig. 8-1c and d).

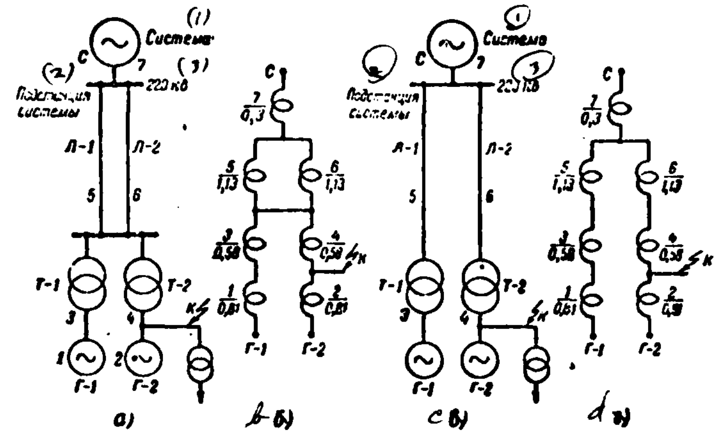

Fig. 8-1. Diagrams to example of 8-1.

Key: (1). System. (2). substation of system. (3). kV.

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The resulting resistor/resistance from G-1 and C

$$\frac{(x_1+x_3+x_5)\,x_7}{x_1+x_3+x_5+x_7}+x_4+x_6=$$
$$=\frac{(0{,}81+0{,}58+1{,}13)\,0{,}3}{0{,}81+0{,}58+1{,}13+0{,}3}+0{,}58+1{,}13=1{,}98,$$

then

$$i_y=1{,}8\sqrt{2}\cdot\frac{36{,}7}{1{,}98}+1{,}9\sqrt{2}\cdot\frac{36{,}7}{0{,}81}=169\ \text{kA}$$

i.e. is less by 37 kA cr to 18o/o.

The limitation of short-circuit currents in general:

1) raises the reliability of the work of settings up and decreases the probability of damaging electrical equipment during the short circuits;

2) make it possible to establish/install simpler and cheaper electrical equipment (apparatuses, current-carrying parts, etc.) as a result of the possibility of its selection to smaller short-circuit currents.

8.2. Separate work of transformers and feeding lines.

A substantial limitation of short-circuit currents on the secondary side of the reducing substations is achieved at the separate work of transformers. This is evident from the fact that if the calculated resistor/resistance of short circuit to point K with the multiple operation of transformers (Fig. 8-2a, sectionalizing switch CB it is connected) comprises (when $S_б = S_{c.ном}$) $x_{*расч} = x_{*c} + \frac{u_к\%}{2\cdot 100}\frac{S_{c.ном}}{S_{т.ном}}$, then with the separate work of the transformers (Fig. 8-2b, CB it is disconnected) it increases to $x_{*расч} = x_{*c} + \frac{u_к\%}{100}\frac{S_{c.ном}}{S_{т.ном}}$. Here x_{*c} - inductive reactance of system to

busbars U_1, in reference to its nominal power. Is the less x_{*c}, the more changes $x_{*расч}$, the short-circuit current with the separate work of transformers. In limit when $x_{*c}=0$ $(S_{c.ном}=\infty)$ because of the separate work of current transformers of short circuit at point K will be 2 times less, rather than with the multiple operation of transformers.

With the separate work of transformers usually somewhat at the same time increase the loss of electric power in them as a result of different load of transformers, by the caused different load S_1 and S_2 sections of collecting mains by voltage U_2. However, this increase of the transformer losses, as a rule, is small; therefore in practice they consider economically advisable to apply the separate work of the step-down transformers in all cases when this is desirable from the conditions of limiting the short-circuit currents.

Exception/elimination can be the powerful/thick substations, at secondary voltage of which are established/installed the synchronous condensers, employees for consumption/production/generation and delivery into the network/grid of the system of reactive power (cm Chapter 22). Under these conditions frequently there is hindered/hampered or even impossible the separate work of transformers due to condition into the network/grid of reactive/jet power, developed by compensators, and it is necessary to retain the multiple operation of transformers resorting to other methods of

limiting the short-circuit current which are presented below.

Powerful/thick and critical installations frequently supply along two electric power lines (Fig. 8-3a). It is obvious that also in this case separate work of the feeding lines with the off sectionalizing switch CB on substation (Fig. 8.3b) gives the smaller values of short-circuit currents in network/grid, for example at point K.

In circular electric systems for reduction in current of short circuit it is possible to hold the ring of lines by normally extended on one of the substations of network/grid.

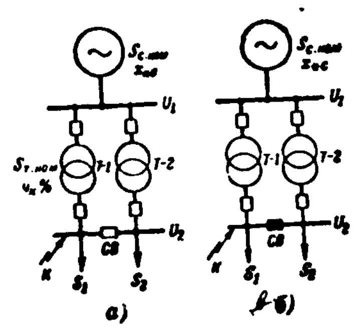

Fig. 8-2.

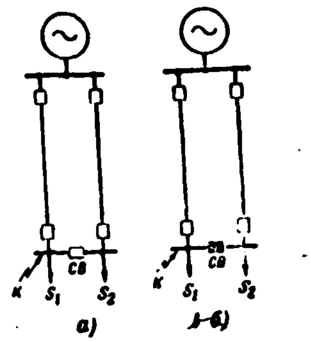

Fig. 8-3.

Fig. 8-2. Diagrams of substation with parallel (a) and separate (b) work of transformers.

Fig. 8-3. Diagrams of substation with parallel (a) and separate (b) work of feeding lines.

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Let us note that with the separate work of transformers and lines the steadiness of feed by electric power of users is provided by special automatic devices/equipment (AVR - automatic input unit of reserve), which switch on normally off sectionalizing switch SV with emergency cutoff/disconnection of one of the transformers or by one of the lines. The power of each transformer or the capacity of each line must be sufficient for feed load of substation.

Example of 8-2. During three-phase short circuit at point K in the diagram in Fig. 8-2 to determine impact current for the cases of the parallel and separate work of the transformers of substation.

The initial data: $S_{c.ном}=1\,000$ MVA; $x_{*c}=0,6$; $S_{т.ном}=120$ MVA; $u_к=10,5\%$. $U_1=115$ kV; $U_2=10,5$ kV.

We accept $S_б=S_{c.ном}=1\,000$ MVA and we lead to it the resistor/resistance of the transformers

$$x_{*т.б}=0,105\frac{1\,000}{120}=0,88.$$

With $U_б=U_{ср}=10,5$ kV we determine

$$I_{ном\Sigma}=\frac{1\,000}{\sqrt{3}\cdot 10,5}=55 \text{ kA}.$$

Short circuit with the connected sectionalizing switch CB:

$$x_{*расч}=0,6+\frac{0,88}{2}=1,04;$$

$$I''=\frac{55}{1,04}=53 \text{ kA} \quad \text{and} \quad i_y=1,8\sqrt{2}\cdot 53=135 \text{ kA}.$$

Short circuit with the off sectionalizing switch CB:

$$x_{\text{эрасч}} = 0{,}6 + 0{,}88 = 1{,}48;$$

$I'' = \frac{55}{1{,}48} = 37$ kA and $i_y = 1{,}8\sqrt{2}\cdot 37 \approx 95$ kA, i.e., it is less approximately/exemplarily to 30o/o.

8.3. Use/application of transformers with split windings.

In certain cases at electrical stations and substations can be used the transformers with split windings, with which is achieved a substantial limitation of short-circuit currents.

Transformer with multiple winding - this is multicircuit transformer in which two or more than winding are designed for one voltage and are utilized for a connection to the different sections of the collecting mains of station or substation (Fig. 8-5c; sectionalizing switch CB is normally disconnected).

Most use extensively powerful/thick transformers with the split low-voltage windings, as shown in Fig. 8-4a and c for transformers to two and three voltages. Both circuits of split winding are designed for identical power (usually to 50o/o of nominal power of transformer) and possess identical resistor/resistance. The cost/value of such transformers barely differs from the cost/value of the transformers of normal construction/design.

In the necessary cases the transformers can be performed with

splitting/fission of windings into three, four and more than circuit, which, however, complicates their construction/design and increases their cost/value.

The characteristic values of transformers with split windings as triple-wound transformers, they are voltages of short circuit for each pair of windings with the idling of the third winding. For transformers with two voltages and multiple low-voltage windings such values are $u_{кВ-Н}$ and $u_{кН-Н}$ (Fig. 8-4a), and also $u_{кВ-Н//Н}$, defined with parallel connection of the circuits of the split low-voltage winding, i.e., as for a usual double wound transformer without splitting/fission of its windings.

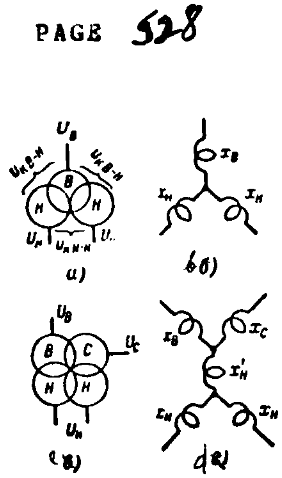

Fig. 8-4. Schematics of transformers with split windings.

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The replacement scheme of transformer by two voltages with the split low-voltage windings is given in Fig. 8-4b (for one phase). Inductive winding impedances determine from the following conditions:

Through inductive reactance (with parallel connection of low-voltage windings)

$$x_{\text{скв}} = u_{\text{кВ-Н//Н}} = x_{\text{В}} + 0{,}5x_{\text{Н}}. \qquad (8\text{-}1)$$

Singe-circuit inductive reactance (one of the low-voltage windings is disconnected)

$$x_{\text{одн}} = u_{\text{кВ-Н}} = x_{\text{В}} + x_{\text{Н}}. \qquad (8\text{-}2)$$

Mutual inductive reactance or inductive reactance of the splitting/fission (winding B is disconnected)

$$x_{\text{расщ}} = u_{\text{кН-Н}} = 2x_{\text{Н}}. \qquad (8\text{-}3)$$

From conditions (8-1) and (8-3) we obtain:

$$x_{\text{В}} = u_{\text{кВ-Н//Н}} - 0{,}25u_{\text{кН-Н}} = x_{\text{скв}} - 0{,}25x_{\text{расщ}}, \qquad (8\text{-}4)$$

while from condition (8-3)

$$x_{\text{Н}} = 0{,}5u_{\text{кН-Н}} = 0{,}5x_{\text{расщ}}. \qquad (8\text{-}5)$$

Here all values x and $u_{\text{к}}$ must be expressed in relative unity at the nominal power of transformer.

Transformers can be performed for different relationships/ratios $\frac{u_{\text{кН-Н}}}{u_{\text{кВ-Н//Н}}} = \frac{x_{\text{расщ}}}{x_{\text{скв}}}$, but the optimum value of this sense is equal to 4 [8-1]. Soviet plants manufacture powerful/thick single-phases transformer with split windings whose impedance voltage $u_{\text{кВ-Н/Н}}$ is received by the same as in the usual double wound transformers of the same power also to the same voltages, when $x_{\text{расщ}} = 4x_{\text{скв}}$.

Under these conditions for Soviet transformers with split windings:

$$x_{\text{В}} = 0 \text{ и } x_{\text{Н}} = 2x_{\text{скв}} = 2u_{\text{кВ-Н//Н}}. \qquad (8\text{-}6)$$

Therefore in the extreme case when the resistor/resistance of system to transformer (tc winding B) can be taken as equal to zero ($x_{*B}=0$ and $x_{*C}=0$). then of short circuit on side of one of split windings H is limited only to one resistor/resistance x_H independent of presence or absence of power supplies from the side of the second winding H. But if we consider that resistor/resistance x_H is 2 times more than inductive reactance of double wound transformer without splitting/fission of windings, then in the limiting case in question with split windings short-circuit current on the side of winding H will be 2 times less, rather than with the transformer of the same power, but without split windings.

Via analogous reasonings it is possible to determine winding impedances of transformer during splitting/fission of low-voltage winding on three and more than circuit or during splitting/fission of the winding of another voltage.

If transformer has three voltages with the split low-voltage winding, then winding impedances can be calculated according to formulas [4-1, Section 35]:

$$\left.\begin{aligned}
x_B &= 0,5\,(u_{\kappa\,B-C} + u_{\kappa\,B-H} - u_{\kappa\,C-H});\\
x_C &= 0,5\,(u_{\kappa\,B-C} + u_{\kappa\,C-H} - u_{\kappa\,B-H});\\
x'_H &= 0,5\,(u_{\kappa\,B-H} + u_{\kappa\,C-H} - u_{\kappa\,B-C}) - 0,25u_{\kappa\,H-H};\\
x_H &= 0,5u_{\kappa\,H-H}.
\end{aligned}\right\} \quad (8\text{-}7)$$

Here $u_{\kappa\,B-C}$, $u_{\kappa\,B-H}$ and $u_{\kappa\,C-H}$ - impedance voltage of triple-wound transformer without splitting/fission of its windings.

For single-phases transformer with concentric windings during their usual location relative to core (near core - winding HH, then winding CH and the outer winding BH) it is possible to accept:

$$u_{\kappa\,H-H} = x_{расщ} = 4u_{\kappa\,C-H}. \qquad (8\text{-}8)$$

Example of 8-3. To compare the strengths of impact currents during three-phase short circuit at points K-1 on diagrams in Fig. 8-5a and c.

The initial data:

Hydraulic generators G-1 and G-2: $S_{г.ном} = 85{,}5$ MVA; $U_{г.ном} = 10{,}5$ kV; $x''_{*d} = 0{,}24$; have damping windings.

Transformer T; group of three single-phases transformer with a power of $S_{т.ном} = 3 \cdot 60 = 180$ MVA; $u_{\kappa} = 10{,}5\%$; for single-phases transformer with the split low-voltage windings $u_{\kappa\,B-H'/H} = 10{,}5\%$ and $u_{\kappa\,H-H} = 4u_{\kappa\,B-H'/H}$.

System C: $S_{с\,ном} = 500$ MVA, $x_{*с} = 0{,}7$.

We accept $S_б = 100$ MVA and $U_б = U_{cб} = 10{,}5$ kV; then $I_б = 5{,}5$ kA.

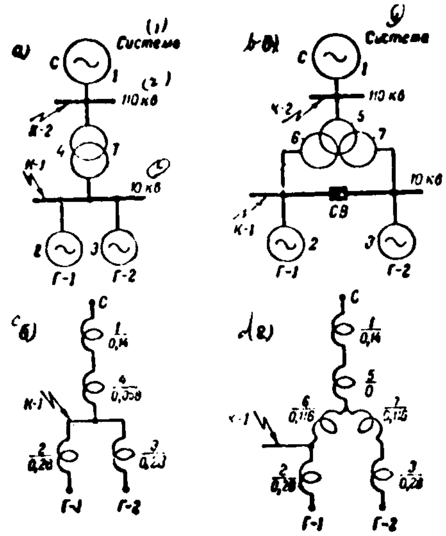

Fig. 8-5. Diagrams for example of 8-3.

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For both versions we connect of substitution (Fig. 8-5b and c) and indicate them the resistors/resistances, led to base line power. For a version with the split low-voltage windings according to conditions (8-6) $x_B = 0$ and $x_H = 2 \cdot 0{,}105 = 0{,}21$, then $x_5 = 0$ and

$$x_6 = x_7 = x_H \frac{S_б}{S_{т.ном}} = 0{,}21 \frac{100}{180} = 0{,}116.$$

In both versions short-circuit current on generator G-1 one and the same, since it does not depend on the type of the adjustable transformer. Let us determine this current by formula (6-55), after accepting on Table 6-1 for a hydraulic generator with damper windings

when $x''_{*d} = 0{,}24$ coefficient $k \approx 1{,}09$:

$$I''_{Г\text{-}1} = \frac{1{,}09 \cdot 5{,}5}{0{,}28} = 21{,}4 \text{ kA} \text{ and } i_y = 1{,}9\sqrt{2} \cdot 21{,}4 = 58 \text{ kA}.$$

Calculation for the first version (Fig. 8-5a and b).

For the branch of system k=1; therefore

$$I''_c = \frac{5{,}5}{0{,}14 + 0{,}058} = 27{,}8 \text{ kA}.$$

Current from generator $Г\text{-}2$ $I''_{Г\text{-}2} = I''_{Г\text{-}1} = 21{,}4$ kA.

Impact current from system and generator G-2 $i_y = 58 + 1{,}8\sqrt{2} \cdot 27{,}8 = 129$ kA, but taking into account generator $Г\text{-}1$ $i_y = 129 + 58 = 187$ kA.

Calculation for the second version (Fig. 8-5c and d).

For the branch of system and second hydraulic generator we accept how for the case of different types of generators, k=1.

Resulting resistor/resistance from system and second generator

$$\frac{x_1(x_2+x_3)}{x_1+x_2+x_3}+x_4=$$
$$=\frac{0,14\,(0,28+0,116)}{0,14+0,28+0,116}+0,116\approx 0,22.$$

Current from system and second generator $I_c''=\frac{5,5}{0,22}=25$ kA and $i_y=1,8\sqrt{2}\cdot 25\approx 64$ kA, but taking into account generator G-1 $i_y=64+58=122$ kA.

Thus, because of the use/application of a transformer with split winding the flowing into point K-1 impact short-circuit current changed: from system and generator G-2 - in $\frac{129}{64}\approx 2$ the time, and full/total/complete value - in $\frac{187}{122}\approx 1,5$ time, which, of course, substantially manifests itself when selecting of electrical equipment of generator voltage.

Since through inductive reactance of transformer with split windings is equal to inductive reactance of usual transformer without splitting/fission of windings, then, obviously, the value of short-circuit current during short circuit at the increased voltage at point K-2 in both cases will be identical.

In the second version of diagram in Fig. 8-5c sectionalizing switch CB of normal is disconnected and generators work in parallel through the transformer with split windings. With cutoff/disconnection of one of the generators switch CB must be

connected so that the corresponding section of the busbars of generator voltage would be supplied directly from remaining in work generator. This prevents/warns the return flow of power through the split circuits of the low-voltage windings of transformer, which is conjugated/combined with the considerable losses of voltage and energy.

8.4. Use/application of reactors.

Reactor is coil with the low active resistor/resistance; the turns of coil are isolated/insulated from each other, and entire coil as a whole is isolated/insulated from the grounded parts. Coil is fastened on framework/body from insulating material (see Fig. 8-14)

The ends/leads of the windings are equipped with terminals/grippers for the series connection of reactor into network/grid. In three-phase settings up are applied the reactors, which consist of three coils.

Reactor is characterized by rated current $I_{p.ном}$, nominal voltage $U_{p.ном}$ and inductive reactance in percentages $x_p\%$. The latter is determined from the following formula (see Chapter 6):

$$x_p\% = \frac{\sqrt{3}\, x_p I_{p.ном}}{U_{p.ном}} 100, \qquad (8\text{-}9)$$

where $x_p = \omega L 10^{-3}$ [ohm] with the inductance of reactor L, expressed in

millihenry.

The effective resistance of reactor is insignificant; therefore during calculations of short-circuit currents of its they do not consider.

The reactors, used for limiting the short-circuit currents, are performed without steel cores so that the inductance their L and, consequently, also inductive reactance x_r would not depend on the current, flowing on the winding of reactor. If reactor was equipped with steel core, then with the course of short-circuit current would occur the saturation of core and the decrease of the inductance of reactor. Therefore the reactor with steel core, which possesses with the saturated core the inductance, sufficient for the assigned limitation of short-circuit current, would have in the normal mode of work - with unsaturated core - the increased value of inductance, which would lead to the increased loss of voltage in it in the normal mode of work. Furthermore, reactor with steel core is more expensive in it more than energy loss: are added core loss to hysteresis and eddy currents.

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If the circuit into which is connected the reactor, is supplied

from the source of the unlimited power, i.e., if the voltage, conducted/supplied to reactor, in all modes/conditions remains the constant and equal to U_{cp} (condition $x_{*c}=0$), then periodic component/term of short-circuit current during damage after reactor is determined from formula (6-47):

$$I_{\kappa}=I_{p.\text{ном}}\frac{100}{x_p\%},$$

from which it is evident that is the more $x_p\%$ and is the less $I_{p.\text{ном}}$, the less and maximum possible short-circuit current during damage after reactor.

With the feed of circuit from the intallation of final power the ability of reactor to limit short-circuit current is characterized by its relative base line resistor/resistance, determined according to formula (6-20). The greater the relative base line resistor/resistance of reactor, the more it limits short-circuit current.

If we for base line power accept the nominal power of the generators of station or system and respectively in formula (6-20) $I_б$ to replace $I_{\text{ном}\Sigma}$, then it will become obvious, that reactor the more limits the short-circuit current, the less its rated current in comparison with the given rated current of power supplies, or, in other words, the less the power of circuit, into which is connected

the reactor, in comparison with the power of the feeding of installation or system.

Thus, with the same value $x_p\%$, reactors to small rated currents more greatly limit short-circuit currents, rather than reactors to large rated currents.

In the normal mode of work in reactor is certain loss of voltage, the numerically equal to an arithmetical difference in the phase voltages before and after reactor $\Delta U_{\phi}=U_{1\phi}-U_{2\phi}$. Fig. 8-6a gives the diagram of voltage distribution in circuit with reactor during the normal mode of the work, on which is shown the loss of voltage in reactor ΔU_{ϕ}. The dependence between the loss of voltage ΔU_{ϕ} and a drop in voltage $I_{н}x_{р}$ in reactor it is easy to determine from vector diagram in Fig. 8-6b, constructed under the assumption $r_{р}=0$. If we conduct arc with a radius of $U_{1\phi}$, then the loss of voltage will be determined by cut $\overline{бв}=\Delta U_{\phi}=U_{1\phi}-U_{2\phi}$.

In view of the smallness of angle ψ it is possible to accept cut $\overline{гв}=0$ and to assume $\overline{бг}\approx\overline{бв}\approx\Delta U_{\phi}$. From triangle abc we determine $\overline{бг}=\overline{аб}\sin\varphi$ or

$$\Delta U_{\phi}=I_{н}x_{р}\sin\varphi.$$

After substituting the resistor/resistance of reactor in percentages

from formula (8-9) and after producing the necessary transformations, we will obtain:

$$\Delta U\% = x_p\% \frac{I_n}{I_{p.ном}} \sin \varphi. \qquad (8\text{-}10)$$

Since usually $U_{p.ном} = U_{уст\ ном}$, the expression (8-10) makes it possible to determine the loss of voltage in reactor in the percentages of the nominal voltage of setting up with known for load circuit (reactor) I_n.

Power loss in reactors without cores is usually small and composes 0.15-0.4o/o of power, which takes place through the reactor. In spite of this, the annual loss of electric power in reactors can be considerable.

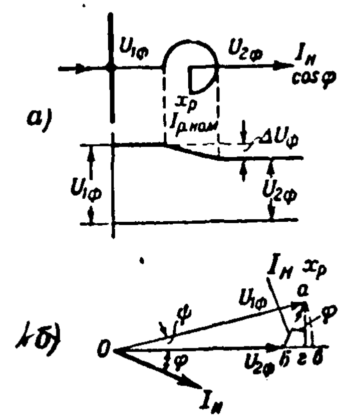

Fig. 8-6. Normal mode of the work of circuit with reactor. a) the diagram of the voltage distribution; b) vector diagram of voltages and currents.

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If is noted for power loss in the coil of the reactor (see table P-7) with load its rated current $I_{р.ном}$, then annual energy loss in the coils of three phases will be determined according to the following formula, known from course "electrical networks" [7-1]:

$$A_{год} = 3\left(\frac{I_{н\ макс}}{I_{р.ном}}\right)^2 \Delta P\tau\ [квт\cdot ч], \qquad (8\text{-}11)$$

where $I_{н.макс}$ - a current of the peak load of circuit (reactor), and;

ΔP - power loss in reactor with rated current, kW;

τ - time of maximum losses which determine depending on $T_{макс}$ (see 4-3) and cos ϕ the loads of circuit according to the diagram, given in appendix 11-8.

Fig. 8-7 gives different circuit diagrams of reactors on electrical stations and substations. During the evaluation/estimate of these diagrams should be considered the losses of voltage and energy in reactors and the effectiveness of the limitation by them of short-circuit current.

Reactors P, established/installed in the circuits of generators (Fig. 8-7a), limit the currents of short during closings/shortings both within the limits of station itself - in the circuits of generators and waste/exiting lines, on collecting mains both in other circuits and at any point of electric system, which feeds from station. A deficiency/lack in the diagram is small limitation of short-circuit current as a result of the large rated current of reactors ($I_{р.ном} \geqslant I_{г.ном}$) with their comparatively small inductive reactance - not more than 6-8o/o. Latter/last limitation is caused by the loss of voltage in the reactors through which flows/occurs/lasts entire/all manufactured by generators electric power. So, if generators work with cos φ=0.8, then according to formula (8-10) the

loss of voltage in reactors with inductive reactances indicated with full load will compose 3.6-4.8o/o. With respect to this for guaranteeing normal stress on the collecting mains of station load voltage of generators must be supported to 3.6-4.8o/o of higher than their nominal voltage (generators of domestic manufacture can long work with voltages, that exceeds their nominal voltage to 10o/o inclusively; however, with increase voltages more than on 5o/o generators cannot be loaded to their nominal power - see §22-1).

Besides that indicated, in the diagram a in question the value of short-circuit current on the collecting mains of station increases proportional to a number of connected generators; therefore in this diagram it is not possible to fulfill powerful/thick station to a large number of aggregates/units. In this diagram are considerable also the annual losses of electric power in reactors. All this tells the inexpediency of reactor shutdown in the circuit of the generators of power plants.

In diagram b are established/installed the sectional reactors PC-1 and PC-2, connected in series into collecting mains. The waste/exiting lines distribute between sections so that they as far as possible would be loaded equally. Therefore in the normal mode through sectional reactors flow/occur/last small currents and power losses and energy in them they are small.

Sectional reactors limit currents during short circuits both at station itself and in its electric system. However, short-circuit currents from the generators of different sections are limited differently.

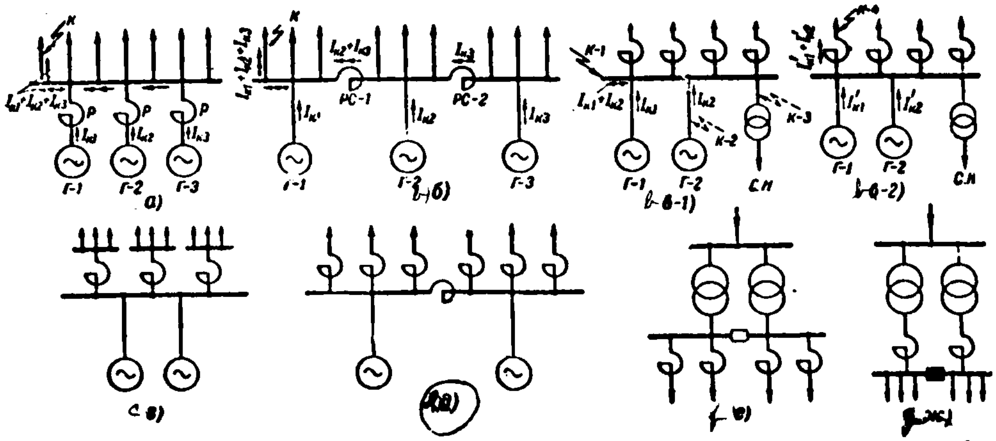

Fig. 8-7. Sites of installation of reactors in the diagrams of connections of electrical stations and substations.

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So, during short circuit at point K in the diagram b current $I_{\kappa 1}$ from generator G-1 is not limited to sectional reactors, current $I_{\kappa 2}$ from generator G-2 is limited by one sectional reactor PCh-1, but current $I_{\kappa 3}$ from generator G-3 is limited by the already two reactors: PC-1 and PC-2; therefore $I_{\kappa 1} > I_{\kappa 2} > I_{\kappa 3}$.

With the cutoff/disconnection of generator of one of the sections through the sectional reactor flows/occurs/lasts the current of load, necessary for the feed of the waste/exiting lines of the section of the disconnected generator. In the majority of the cases

sectional reactor proves to be loaded to the current, which does not exceed 60-80o/o of the rated current of generator. To this current must be selected sectional reactor.

Of the condition of limiting the short-circuit current it is desirable to have largest possible resistor/resistance of sectional reactors. But taking into account that in the normal mode through sectional reactors certain current nevertheless flows/occurs/lasts (caused by the in practice different load of sections), for warning/preventing the considerable difference of voltages in sections apply sectional reactors with resistor/resistance to 8-10o/o and as an exception 12o/o.

Thus, with the aid of only the sectional reactors, which possess large rated current during a comparatively small resistor/resistance, it is not possible to considerably restrict short-circuit current, especially if one considers that from one of the current generators of short circuit remains unconfined (in the diagram b - current $I_{к1}$ from generator G-1). With the aid of some sectional reactors it is possible to attain the necessary limitation of short-circuit current only on power plants with a small number of generators of comparatively small power.

If during the design of the power plants of small and

average/mean power appears the need of limiting the short-circuit currents, then always should be checked the possibility of applying this method of reactance/reacting as an economically very advisable as a result of a small number of reactors small increase in the capital expenditures and small annual energy losses in reactors.

With an increase in the number of sections the short-circuit current in diagram b grows/rises proportional to a number of sections, but it is considerably slower. In more detail than the diagram of stations with the reacted collecting mains they are examined in Vol. 2.

On diagrams b-1 and b-2 is shown the installation of reactors on cable lines by the voltage 6-10 kV of power plants. Reactors in lines decrease the short-circuit current only during closing/shorting in network/grid, i.e., on line after reactor. Actually/really, during short circuit on the collecting mains of station at point K-1 (diagram b 1) the short-circuit current from generators to reactors is not limited. Is not limited it, also, during closings/shortings in the circuits of generators (K-2) or during connections to the collecting mains, not equipped with reactors (K-3).

In the case of closing/shorting on line after reactor (K-4 in the diagram b-2) the short-circuit current is considerably limited to

the resistor/resistance of the reactor

$$I'_{к1}+I'_{к2}<I_{к1}+I_{к2}.$$

The rated current of reactors on the waste/exiting lines is usually small; therefore they considerably limit short-circuit current, even with the small value of their inductive reactance. The latter can reach 8-10o/o, but when in normal mode the loss of voltage in reactors does not exceed 5o/o [it is determined from formula (8-10)].

During short circuits in network/grid the loss of voltage in the reactor of line makes it possible to support at the collecting mains of setting up considerable voltage, as is evident from the diagram of voltages on Fig. 6-1. The greater the value of residual voltage, the less affects the short circuit the work of the electrical receivers of the sound lines, connected to the same collecting mains.

the value of the residual voltage, supported by reactor at collecting mains, can be determined by formula (6-51). After accepting short circuit on line directly after reactor and after expressing the resistor/resistance of reactor in percentages, after the transformation of the formula indicated we will obtain:

$$U_{ост}\% = x_р\% \frac{I_к}{I_{р.ном}}. \quad (8\text{-}12)$$

Usually $U_{ост}$ they determine when $I_к = I''$. When $U_{р.ном} = U_{уст.ном}$ for formula (8-12) it makes it possible to determine residual voltage in the percentages of the nominal voltage of installation.

The value of residual voltage is not calibrated.

Deficiencies/lacks in the limitation of short-circuit currents with the aid of reactors on lines (diagram c) are: the need installation of a large number of reactors, that very complicates construction/design and operation of distributor and increases its cost/value, essential energy losses in reactors and finally the need of regulating the voltage on the collecting mains of installation taking into account the loss of voltage in the reactors of lines.

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In spite of this, diagram in they use extensively on those power plants of the small and average/mean power where is not required the limitation of short-circuit current in the circuits of generators also on collecting mains.

With a large number of waste/exiting lines of small power apply group reactors (diagram c), than they can be achieved/reached the considerable decrease of a number of reactors and the reduction of

prices of the distributor of station.

In diagram b is provided the installation of sectional reactor and reactors on departing lines how is achieved the limitation of short-circuit currents at closings/shortings both at station itself and in its electric system. Diagram is used extensively on powerful/thick heat and power plants.

On substations, as noted above, the very effective method of limiting the short-circuit current at secondary voltage is the separate work of transformers. If this action is insufficient or is impossible, then are established/installed reactors in departing cable lines as this shown in the diagram f. In this case is economically advisable the multiple operation of the transformers (CB is connected). However, with very powerful/thick transformers additionally can be used their separate work (CB is disconnected), which leads to reduction in current of short circuit on the collecting mains of secondary voltage, and sometimes also to the possibility of installation on the waste/exiting lines of reactors with smaller inductive reactance (with the same short-circuit current in network/grid).

Reactors in the circuits of the step-down transformers substations (diagram g) it is expedient to establish/install when

with the separate work of the transformers (CB is disconnected) it is possible to refuse from installation a large number of reactors on the waste/exiting lines. These reactors similar to reactors in the circuits of generators cannot significantly restrict short-circuit current; therefore with the multiple operation of transformers effect from their use/application is small.

The possibility of installation of reactors in the circuits of transformers must be checked from the conditions for voltage error in users in different operating modes. Most simply this problem is solved during setting up on the substation of transformers with regulating of load stress (see Chapter 23).

Sectional reactors on substations they do not apply, since they greatly little limit short-circuit current.

On waste/exiting aerial lines by voltage higher than 1000 in reactors are not established/installed, since considerable inductive resistance of these lines (~0.4 ohm/cm) sufficiently limits the current of short circuit on the reducing substations.

The greatest possible value of inductive reactance of the reactors, adjusted in the circuits of cable lines and power transformers, is limited by the loss of voltage in them in the normal

mode of work. In this respect more favorable conditions occur during the installation up of the so-called double reactors which in recent years begin to apply on electrical stations and substations.

The doubled reactor is structurally/constructurally similar/such to usual reactor and differs from it in terms of the presence of conclusion/output from the middle of winding (Fig. 8-8a). Both branches (half, section) of the doubled reactor are arranged/located with one above another in the identical direction of the turns of winding.

It is normal both branches and extreme conclusions (A_1 and A_2) are performed to identical rated current. Average conclusion (A) usually is utilized for the connection of supply of power (Fig. 8-8b and c); therefore it occurs calculated for dual current.

Inductance L of the branches of reactor are identical; therefore inductive reactance of each branch of reactor with absence of current in another branch it comprises $x_s = \omega L$ (Fig. 8-8b).

Let us determine inductive reactance of the branch of the doubled reactor with course by its branches of the identical currents of load. This case is given in Fig. 8-8c, where the power supply is connected to the average output A of reactor, and identical loads -

to by the extreme conclusion/output A_1 and A_2. The effective resistance of windings reactors we do not consider.

Both branches of the doubled reactor are magnetically connected with mutual inductance M. A voltage drop in the branch of reactor with equal currents in branches comprises:

$$\Delta U = \omega LI - \omega MI.$$

From theoretical electrical engineering it is known that the degree of the inductive coupling of two coils characterizes coupling coefficient $k_{св} = \frac{M}{\sqrt{L_1 L_2}}$, where L_1 and L_3 - inductance of coils, but M - their mutual inductance.

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In the case of the doubled reactor $L_1 = L_2$; therefore for it coupling coefficient $k_{св} = \frac{M}{L}$. Under this condition a voltage drop in the branch of reactor will be:

$$\Delta U = \omega LI - \omega Lk_{св}I = x_в I - x_в k_{св} I = \\ = (1 - k_{св}) x_в I = x'_в I,$$

where

$$x'_в = (1 - k_{св}) x_в \quad (8\text{-}13)$$

it is inductive reactance of the branch of the doubled reactor under

conditions indicated above.

The value of coupling coefficient depends on the design of the doubled reactor. Usually $k_{cв}=0,4-0,5.$

From formula (8-13) it is evident that during the use of the doubled reactor on diagram in Fig. 8-8c inductive reactance of its branch decreases to value $x'_{в}$, which when $k_{cв}=0,5$ is 2 times less $x_{в}$. Respectively decreases the loss of voltage in normal mode.

From the aforesaid it is possible to draw the conclusion that if inductive reactance of usual reactor x_{p} is equal to inductive reactance $x_{в}$ of the branch of the doubled reactor and rated currents of both reactors are also equal, then with the equal currents of load in both branches of the doubled reactor the loss of voltage in each of its branches will be less than the loss of voltage in usual reactor $\frac{1}{1-k_{cв}}$ once (when $k_{cв}=0,5-2$ times).

During the use of the doubled reactor on diagram in Fig. 8-8d (conclusion/output A - idle) the currents in both branches of reactor are equal and directed to one side; therefore a total voltage drop in reactor will comprise

$$\Delta U = 2\omega LI + 2\omega MI = 2\omega LI + 2\omega Lk_{св}I = 2x_{в}(1 + k_{св})I = x_{скв}I,$$

where

$$x_{скв} = 2x_{в}(1 + k_{св}) \qquad (8\text{-}11)$$

it is through inductive resistance of both branches of the doubled reactor with the course in them of current in one direction (during the addition of magnetic fields of both branches of reactor).

If $k_{св}=0{,}5$, then $x_{скв}=3x_{в}$. It is obvious that to utilize the doubled reactor with the return flow of power in normal mode from one conclusion/output A_1 to next A_2 (or vice versa) is inexpedient as a result of the large loss of voltage in reactor.

The replacement scheme of the doubled reactor, which considers mutual induction between its branches, is given in Fig. 8-8e. From it it is evident that if the power supply is connected to conclusion/output A, and short circuit occurred from the side of conclusion/output A_1 (or A_2), then short-circuit current is limited to internal resistance $x_{в}$ of the branch of reactor.

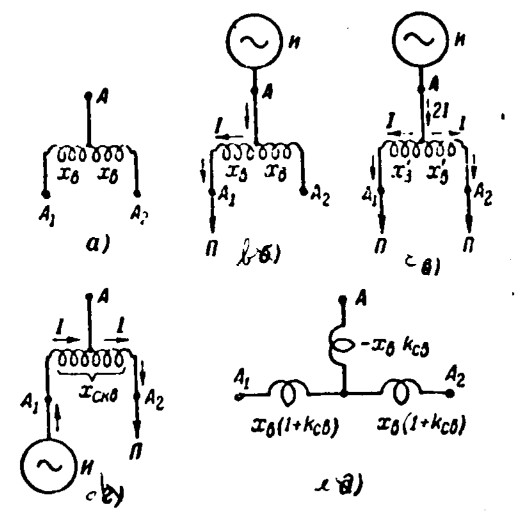

Fig. 8-8. Schematics of the doubled reactors.

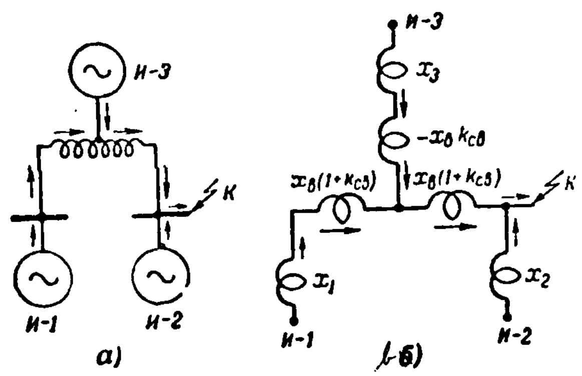

Fig. 8-9. Short circuit in circuit of doubled reactor in presence of power supplies from the side of his all three conclusion/output.

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But if source is connected from the side of conclusion/output A_1 (or

A_2), then during closing/shorting from the side of conclusion/output A_2 (or respectively A_1) short-circuit current is limited to through resistor/resistance $x_{cм}$ of reactor, in $2(1+k_{cв})$ time large $x_н$.

By least favorable is the case of closing/shorting on the side of conclusion/output A with the connection of the energy sources from the side of both the extreme conclusion/output A_1 and A_2, since in this case short-circuit current is limited to resistor/resistance, equal to $0.5x_н(1-k_{cв})$, which when $k_{cв}=0.5$ composes in all $0.25x_в$.

Fig. 8-9a gives the version of the connection of sources from the side of all three outputs of reactor. During short circuit from the side of one of the extreme conclusion/output, for example at point K, resulting resistor/resistance from sources I-1 and I-3 taking into account their resistors/resistances of x_1 and x_3, led to the same base line conditions that also the resistor/resistance of the branches of reactor $x_в$, will comprise (Fig. 8-9b)

$$x_{рез}=\frac{[x_1+x_в(1+k_{cв})](x_3-x_вk_{cв})}{x_1+x_в(1+k_{cв})+x_3-x_вk_{cв}}+x_в(1+k_{cв}).$$

Let us point out that if value $x_3-x_вk_{cв}$ turns out to be with negative sign, which occurs when $x_вk_{cв}>x_3$, then it is possible to accept

$$x_s - x_в k_{св} = 0$$

and to count

$$x_{рез} = x_в(1 + k_{св}).$$

Let us determine the loss of voltage in the branches of reactor with their different load (Fig. 8-10a). For the left branch

$$\Delta U_{\Phi 1} = x_в I_1 \sin \varphi_1 - x_в k_{св} I_2 \sin \varphi_2.$$

Substituting from (8-9)

$$x_в = \frac{x_в\% U_{р.ном}}{100\sqrt{3} I_{р.ном}}$$

and assuming/setting $U_{р.ном} = U_{уст.ном}$, after transformation we obtain the loss of voltage in the left branch of reactor in percentages of $U_{уст.ном}$:

$$\Delta U_1\% = x_в\% \frac{I_1 \sin \varphi_1 - k_{св} I_2 \sin \varphi_2}{I_{р.ном}}. \quad (8\text{-}15,a)$$

It is analogous for the right branch:

$$\Delta U_2\% = x_в\% \frac{I_2 \sin \varphi_2 - k_{св} I_1 \sin \varphi_1}{I_{р.ном}}. \quad (8\text{-}15,b)$$

Let us determine voltage on the extreme output A_1 of reactor during short circuit from the side of another extreme conclusion/output A_2 (Fig. 8-10b). For simplification let us assume that during short circuit on conclusion/output A_2 another branch of reactor runs idle ($I_1=0$). During three-phase short circuit at point K the voltage on conclusion/output A_2 is equal to zero. Interphase

voltage from the side of supply of power

$$U_{к} - U_{A} = \sqrt{3} x_{в} I_{к}.$$

The short-circuit current, flowing on one branch of reactor, induces in its another branch of emf, equal to $x_{в} k_{св} I_{к}$ and that having the same direction, as voltage $x_{в} I_{к}$. Therefore interphase voltage on conclusion/output A_1 will comprise

$$U_{A1} = \sqrt{3}(x_{в} I_{к} + x_{в} k_{св} I_{к}) = \sqrt{3} x_{в} (1 + k_{св}) I_{к}.$$

After replacing $x_{в}$ through $x_{в}\%$ and after accepting $U_{р.ном} = U_{уст.ном}$, we obtain:

$$U_{A1}\% = x_{в}\% (1 + k_{св}) \frac{I_{к}}{I_{р.ном}}. \qquad (8\text{-}16)$$

Since short-circuit current can exceed the rated current of reactor 9-10 times, then, as this follows from formula (8-16), with the course of short-circuit current in one branch of reactor load voltage of the second branch can considerably exceed the nominal voltage of reactor and reach value (1.2-1.35) $U_{р.ном}$ [8-2]. For example, when $x_{в} = 8\%$; $k_{св} = 0{,}5$; $I_{р.ном} = 750\ a$ and $I_{к} = 8\ ка$ and load voltage of intact/uninjured/undamaged branch will comprise

$$U_{A1} = 8(1 + 0{,}5)\frac{8}{0{,}75} = 128\%.$$

If we consider the load of the intact/uninjured/undamaged branch of reactor, then an increase in the voltage on it will be somewhat

less due to the additional loss of voltage in this branch from the current of load.

The increase in the voltage indicated on the intact/uninjured/undamaged branch of reactor during short circuit on its another branch is an essential deficiency/lack in the doubled reactors.

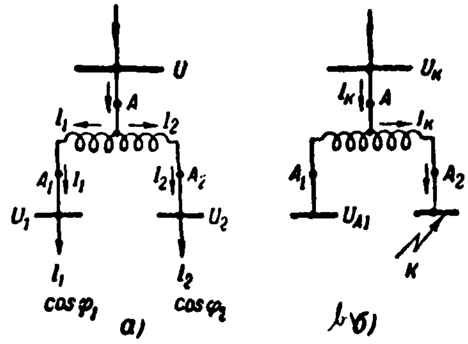

Fig. 8-10. Schematics of the doubled reactors to the determination of voltage on conclusion/output. a) in the normal mode of the work; b) during short circuit on one conclusion/output.

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However, as a result of the short duration of these increases in the voltage (only to the period of short circuit - usually not more than 0.3-1.5 s) they are not dangerous for the insulation of the electrical apparatuses of conductors and electric motors, connected to the line on which occurred an increase in the voltage. Virtually these short-term increases in the voltage do not manifest themselves the work of electric motors, and thereby they do not affect also the work of the mechanisms, connected with these engines. As a result of the short general/common/total duration of such increases in the voltage during year they do not manifest themselves also the service life of incandescent lamps.

The sites of installation of the doubled reactors in the diagrams of electrical stations and substations are shown in Fig. 8-11. The doubled reactors can be applied on the waste/exiting cable lines (diagram a); in this case each reactor is utilized for the feed of two lines, which 2 times decreases a number of reactors in comparison with usual reactors. Descend also the losses of voltage in reactors in the normal mode of work. An even larger savings is reached at the use/application of the group doubled reactors on diagram b.

On diagrams c and d is shown the use of the doubled reactors as sectional ones. In diagram c they are connected in the circuit of generators, while in diagram c - into the circuit of the step-up transformer. In powerful/thick stations additionally are installed the reactors on the waste/exiting cable lines.

In the diagram e the doubled reactor is used in the circuit of the step-down transformer substation. On powerful/thick substations additionally can be established/installed the reactors on the waste/exiting cable lines.

Let us note that the effectiveness of the use/application of the

doubled reactors in the circuits of the powerful/thick step-up and step-down transformers always should be compared with the effectiveness of the use/application of transformers with split windings, if, of course, such transformers can be prepared.

8-5. Selection of reactors.

Reactors are selected on nominal voltage, rated current and inductive reactance in percentages.

The nominal voltage of reactor select in accordance with nominal voltage of installation. In this case one should consider that the reactors reliably work with the voltages, which exceed their nominal voltage on 10o/o. So, reactors to nominal voltage 6 kV can be applied in installations with voltage to 6.6 kV, and reactors to nominal voltage 10 kV - in installations by voltage to 11 kV.

The rated current of reactor (branch of the doubled reactor) must not be less than the maximum prolonged current of the load of circuit, into which it is connected:

$$I_{р.ном} \geq I_{н.макс}.$$

Inductive reactance of reactor determine on the basis of condition the limitations of the current (or power) of short circuit

to the assigned value. In this case for reactors on the waste/exiting cable lines of electrical stations and substations the determining conditions they are: 1) the thermal resistance of power cables, run in this electric system, 2) the types of the switches which it is assumed to establish on the waste/exiting lines in this installation and on the reducing substations of its electric system (switches on the reacted lines of this setting select on short-circuit current after the reactors of line, for greater detail, see Chapter 21).

For determining inductive reactance of reactors from the first condition must be known the sections of the cables of the electric systems, selected according to the conditions of the normal mode of the work (see Chapter 11). If some of these cables are not thermostable during short circuits, then they determine, at what value $I_{\omega\, расч}$ overheating cables will not exceed that permitted. this current place as basis determinations $x_p\%$.

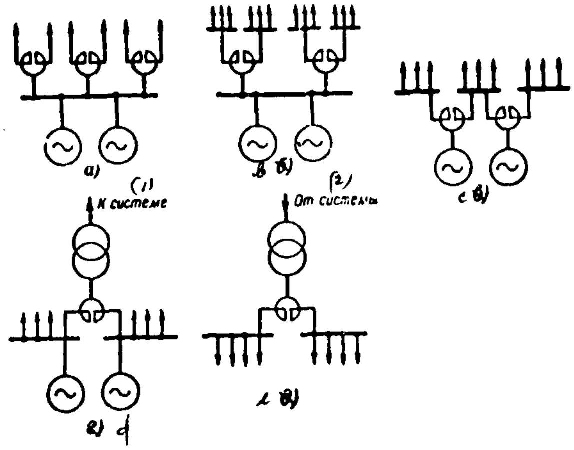

Fig. 8-11. Sites of installation of the doubled reactors in the diagrams of electrical stations and substations.

Key: (1). To system. (2). From system.

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As a result of the considerable resistor/resistance of the reactors of the waste/exiting lines periodic component/term of the current of short during closing/shorting after them changes within the small limits (see curved 4 and 5 in Fig. 6-21). This fact makes it possible approximately to accept during closing/shorting after these reactors $I''_{расч} = I_{\infty расч}$, which simplifies calculations regarding the resistor/resistance of reactors.

For determining the resistor/resistance of reactor from the second condition it is necessary to know, what power or what current can disconnect the switches, which are intended to establish on the waste/exiting lines of this setting and on the substations of its electric system[1].

FOOTNOTE [1]. On the reducing substations in networks/grids 6-10 kV install the high-voltage switches of small overall sizes with power the cutoffs/disconnections to 200-350 MVA (type VMG, VMB, VG-10 and similar to them - see Chapter 17), while on small substations - also safety fuses with the quartz filling of the type PK (see Chapter 14), capable of disconnecting the power of short circuit to 200 MVA.

In the reacted lines of stations and substations usually install oil breakers with small space of oil (types VMG or MGG-10) or air circuit breakers with power the cutoffs/disconnections to 200-500 MVA. ENDFOOTNOTE.

In catalogs or reference tables to the switches (see Table P-14) are indicated current cutoffs/disconnections $I_{отк}$ or the power of cutoffs/disconnections $S_{отк}$ (see Chapter 17), which the switch can disconnect with this voltage of installation.

According to the operating in the USSR rules of the

device/equipment of electrical devices [3-6] the disconnecting ability of switches must satisfy condition $I_{\text{отк}} \geq I''$ (or $S_{\text{отк}} \geq S''$), where I" and S" are determined during three-phase short circuit in this installation (for greater detail, see Chapter 21). Consequently, if they are known the type of switch and its disconnecting ability, then as basis the determinations of the resistor/resistance of reactor on line can be placed ultratransitory current $I''_{\text{расч}} = I_{\text{отк}}$ or ultratransitory power $S''_{\text{расч}} = S_{\text{отк}}$.

Let us examine the order of the selection of reactor for the waste/exiting cable line of station based on the example of the diagram, given in Fig. 8-12. Let us agree that during three-phase short circuit at point K must be observed condition $I''_K \leq I''_{\text{расч}}$ either $S''_K \leq S''_{\text{расч}}$, where $I''_{\text{расч}}$ or $S''_{\text{расч}}$ are determined on the basis of that presented above.

Further accept $S_б$ and $U_б = U_{\text{ср}}$, lead all known resistors/resistances to base line power and connect substitutions (Fig. 8-12b). In the latter are known all relative resistors/resistances, except the base line resistor/resistance of reactor $x_{*р.б}$. Then convert diagram and reduce it to form diagrams in Fig. 8-12c, where through $x_{*\Sigma}$ the markedly total base line resistor/resistance of all network elements to reactor.

Further is determined the value of the resulting resistor/resistance of short circuit, on the basis of assigned magnitude I''_K or S''_K:

$$x_{*рез}=\frac{I_б}{I''_K} \text{ or } x_{*рез}=\frac{S_б}{S''_K}.$$

Relative base line resistor/resistance of the reactor

$$x_{*р.б}=x_{*рез}-x_{*\Sigma}.$$

Resistor/resistance of reactor in its rating factors

$$x_р\%=x_{*р.б}\frac{I_{р.ном}}{I_б}100. \qquad (8\text{-}17)$$

Further using catalogs to reactors or reference tables (see Table P-7), is selected the type of reactor with nearest high inductive reactance.

After this are determined all necessary values of current (power) during short circuit after the selected reactor. For this is determined the calculated resistor/resistance of the circuit:

$$x_{*расч}=x_{*\Sigma}\frac{S_{ном\Sigma}}{S_б}+\frac{x_р\%}{100}\frac{I_{ном\Sigma}}{I_{р.ном}}.$$

If $x_{*расч}<3$, then short-circuit current is defined by calculated curves; when $x_{*расч}>3$ calculation conduct as for the distant point of short circuit.

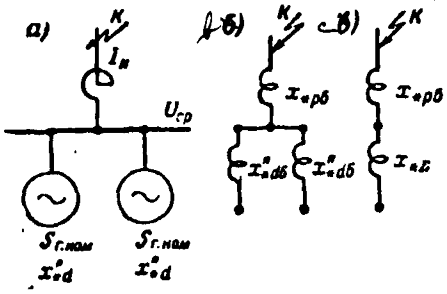

Fig. 8-12. Network (a) and replacement scheme (b and c) to the selection of reactor on line.

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It is possible to select reactor on line and without taking into account all which precede it resistors/resistances, i.e., under the assumption of the unlimited power of the feeding system and $x_{*c}=0$. In this case from formula (6-47):

$$x_p\% = \frac{I_{p.ном}}{I''_K}100 = \frac{\sqrt{3}I_{p.ном}U_{cp}}{S''_K}100. \quad (8\text{-}18)$$

With selected thus reactor the current and the power of short circuit on line at point K never can be more than given ones at any power of station and system. Selection according to this method always gives the resistor/resistance of reactor with certain exaggeration.

The selection of reactors on powerful/thick substations does not differ from that presented above for a power plant. In this case by x_{s} (diagram in Fig. 8-12c) should be understood the total resistance of system and transformers of substation (to the wiring point of reactor). At large power the systems reactors on the waste/exiting lines of substations frequently select without taking into account the resistor/resistance of system ($S_c=\infty$), taking into account only the resistor/resistance of transformers.

Analogously are selected group reactors, and also doubled reactors on the waste/exiting lines. In the latter case is determined inductive reactance of the branch (arm) of doubled reactor $x_{н}$ %.

Sectional reactors on power plants usually are selected on the basis of what switches intend to establish in the main chains of station (switches in the circuits of generators, step-up transformers, transformers of its own needs, switches bus-connecting and sectional). As noted above, on comparatively small power plants sometimes it is possible to be restricted to the installation only of some sectional reactors, without establishing reactors in the waste/exiting lines. In these cases sectional reactors must restrict short-circuit current to such value, with which are provided the thermal resistance of power cables of electric system and the possibility of use/application on the supply-line substations of the

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assigned types of switches and safety fuses.

It is very important to correctly select the rated current of sectional reactor. For this it is necessary to determine the maximum possible constant load of sectional reactor during different modes/conditions of the aggregates/units of station (with cutoff/disconnection of one of the generators, one of the step-up transformers, etc.).

The selected reactor should be checked to electrodynamic and thermal resistance with the course through it of short-circuit current.

The electrodynamic stability of reactor is guaranteed with the observance of the following condition:

$$i_{макс} \geqslant i_y, \qquad (8\text{-}19)$$

where i_y - an impact current during three-phase short closing/shorting after the reactor;

$i_{макс}$ - current of electrodynamic stability of reactor, i.e., maximum current (amplitude value) with course of which through the reactor it is not observed any residual deformation of its windings.

The concrete reactors (see 8-6) with inductive reactance are more than 3o/o against electrodynamic stability it is possible not to check, since plant designs them for greatest possible amplitude current $i_{макс}$, equal to impact current $i_y = 1{,}8\sqrt{2}\,\frac{100}{x_p\%} I_{p.ном}$ with three-phase short circuit after reactor and its feed from the source of the unlimited power.

The thermal resistance of reactor is characterized by plant by value $I_t\sqrt{t}$ (kA•s$^{1/2}$]; therefore the condition for the thermal resistance of reactor takes the form:

$$I_t\sqrt{t} > I_\infty\sqrt{t_\phi}, \qquad (8\text{-}20)$$

where I_∞ - the steady current during short circuit after the reactor;

t_ϕ- fictitious time of action of short-circuit current (see Chapter 7).

With the observance of condition (8-20) heating the winding of reactor during short circuit will not exceed the permissible value.

Example 8-4. To select reactor on the waste/exiting cable line of power plant (Fig. 8-13a), that ensures: 1) the thermal resistance of the cables of the waste/exiting lines of distribution point RP (Kb-1) and station (Kb-2), 2) the possibility of setting up on

distribution points of the network/grid of oil breakers of the type VMB-10 (switches V-1), but on the waste/exiting lines of station - oil breakers of the type VMG-133 (switches V-2).

Fundamental data are given in the diagram.

To additionally accept the following conditions. Cables Kb-1 and Kb-2 to voltage 10 kV have copper veins/strands with paper insulation. Temperature of cores to short circuit normal: $\vartheta_{н}=60°C$.

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The time of action of relaying in the circuit of switch V-1 composes $t_{защ\,1}=1.4$ s, protection in the circuit of switch V-2 $t_{защ\,2}=2.1$ s. Tripping time of switches $t_{в}=0.2$ s.

To additionally to determine the cost/value of the annual losses of electric power in the reactors of the waste/exiting lines of station with the prime cost of electric power 10 kopecks/KW•h. In all from the busbars of station they will move away 14 reacted lines with identical peak load $I_{н.макс}=280$ and with annual total hours of utilization of maximum $T_{макс}=5\,000$ h.

Through table P-14 we find the currents of cutoff/disconnection

with the voltage 10 kV of switches B-1 of the type VMB-10: $I_{отк}=5.8$ kA and switches B-2 of the type VMG-133: $I_{отк}=20$ kA.

Further let us determine, with what value of short-circuit currents is provided the thermal resistance of the assigned cables. For the purpose of simplification in the problem it is possible to consider that during closings/shortings after the reactor of line periodic component/term of short-circuit current in time does not change, i.e., $I''=I_{nt}=I_{\infty}$. This makes it possible to accept $t_{ф}=t=t_{защ}+t_{в}$.

The approximately permissible for a cable short-circuit current can be determined by formula (7-15), after accepting for cables 10 kV with copper veins/strands and paper insulation C=165:

$$I_{к}=I''=I_{\infty}=\frac{sC}{\sqrt{t}}.$$

For cable Kb-1.

the full/total/complete tripping time of the short circuit t=1.4+0.2=1.6 s (aperiodic component/term of short-circuit current we do not consider, since t>1 s) and the permissible short-circuit current

$$I_{к}=\frac{35\cdot 165}{\sqrt{1,6}}\approx 4\,600\ a.$$

Since this current is less $I_{отк}=5.8$ kA for switches B-1, then

reactors on the waste/exiting lines of station must be selected from the condition of guaranteeing the thermal resistance of cables Kb-1, i.e., from condition $I''_{K\cdot 1} \leq 4.6$ kA.

Let us determine the permissible short-circuit current for cable Kb-2. In this case of t=2.1+0.2=2.3 s and $I_{K} = \frac{150 \cdot 165}{\sqrt{2,3}} = 16\,300$ A.

This current is less $I_{\text{отк}} = 20$ kA of switches B-2; therefore reactor must ensure $I''_{K\cdot 2} \leq 16,3$ kA.

Being guided by data of Table P7-1, by the voltage of setting up and by the maximum current of the load of line, we select following rating factors of reactor:

$$U_{\text{р.ном}} = 10 \text{ кв}; \; I_{\text{р.ном}} = 300 \text{ а}.$$

Inductive reactance of reactor we determine on the basis of the maximum permissible short-circuit current during closing/shorting at point K-1.

We connect of the substitution of installation (Fig. 8-13b) we accept $S_{б} = 100$ MVA and we lead to it all known resistors/resistances of circuits (except unknown thus far $x_{*р.б}$). which we indicate in the diagram of substitution.

We determine the total resistance of circuit to point K-1 without the reactor:

$$x_{*\Sigma}=\frac{(0,12+0,26)\,0,2}{0,12+0,26+0,2}+0,22=0,13+0,22=0,35.$$

The resistor/resistance of entire short circuit must be not less:

$$x_{*\text{рез}}=\frac{I_б}{I''_{K\text{-}1}}=\frac{5,5}{4,6}\approx 1,2,$$

where

$$I_б=\frac{100}{\sqrt{3}\cdot 10,5}=5,5\ \text{ка}.$$

The relative base line resistor/resistance of the reactor

$$x_{*\text{р.б}}=x_{*\text{рез}}-x_{*\Sigma}=1,2-0,35=0,85.$$

The resistor/resistance of reactor, in reference to its rating factors, we determine from formula (8-17):

$$x_р\%=0,85\frac{0,3}{5,5}100=4,75\%.$$

On table P7-1, we select a concrete reactor of the type PB-10-300-5, which has $U_{\text{р.ном}}=10$ kV; $I_{\text{р.ном}}=300$ and also $x_р\%=5\%$. The stability of this reactor is characterized by values $i_{\text{макс}}=15,3$ kA and $I_t\sqrt{t}=15$ kA•s$^{1/3}$. Power loss in the coil of one phase ΔP=3.42 kW.

Let us determine current during closing/shorting at point K-2:

$$x_{\text{орез.К-2}} = 0,13 + 0,05\,\frac{5,5}{0,3} \approx 1$$

and

$$I'' = \frac{5,5}{1} = 5,5\ \text{ка}.$$

that less permissible value indicated above $I''_{\text{К-2}}$ for cable Kb-2.

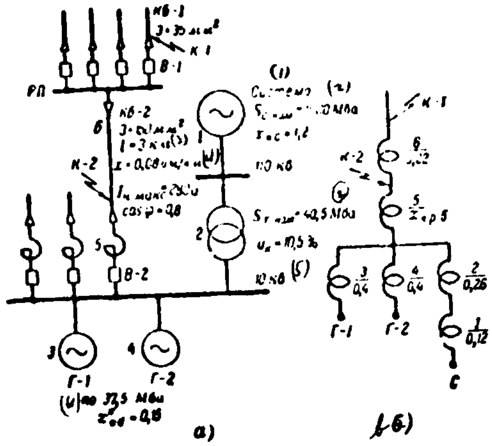

Fig. 8-13. Diagrams for example of 8-4.

Key: (1). Systems. (2). MVA. (3). km. (4). Ω/km. (5). kV. (6). on.

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Since $S_{ном\Sigma} = 1000 + 2\cdot 37{,}5 = 1075$ MVA, then

$$x_{*расч\ К\text{-}2} = x_{*рез.К\text{-}2}\frac{S_{ном\Sigma}}{S_б} = 1\,\frac{1075}{100} = 10{,}75;$$

therefore any point of short circuit after the selected reactor is distant and the previously condition of invariability accepted in the time of periodic of component/term of current was correct.

Check reactor to stability during short circuit after it at point K-2. Since selected concrete reactor from $x_р = 5\%$. that, as noted

above, by electrodynamic stability it it is possible not to check (actually/really, $i_y = 2{,}55 \cdot 5{,}5 = 14$ kA $< i_{макс}$).

Against thermal resistance the reactor is checked according to condition (8-20). In our case $I_\infty = I'' = 5{,}5$ kA and $t_\Phi = t = 2{,}3$ s. Since

$$I_\infty \sqrt{t_\Phi} = 5{,}5\sqrt{2{,}3} \approx 8{,}4\ ка \cdot сек^{1/2} < I_t\sqrt{t} = 15\ ка \cdot сек^{1/2},$$

Key: (1). kA•s.

then reactor is thermostable.

The loss of voltage in reactor in normal mode according to formula (8-10):

$$\Delta U\% = x_p\% \frac{I_{н.макс}}{I_{р.ном}} \sin\varphi = 5\frac{280}{300}0{,}6 = 2{,}8\%,$$

which is completely admissible.

Thus, a reactor of the type RB-10-300-5 can be accepted for installation.

Let us determine the cost/value of the annual losses of electric power in the reactors of 14 waste/exiting lines of station. With assigned $T_{макс} = 5000$ h and $\cos\varphi = 0{,}8$ according to diagram in appendix P-8 we find τ=3600 h. Losses in coil of reactor are known: ΔP=3.42 kW;

therefore according to formula (8-11) we determine the annual losses of electric power in the reactors of all lines:

$$A_{\text{год}} = 14\cdot 3\left(\frac{280}{300}\right)^2 3,42\cdot 3\,600 = 450\,000\ \overset{(1)}{\text{квт}\cdot\text{ч}}.$$

Key: (1) kW•h.

Cost/value of annual losses of electric power in the reactors

$$0,10\cdot 450\,000 = 45\,000\ \overset{(1)}{\text{руб/год}}.$$

by Key: (1). rubles/year.

8-6. Constructions/designs of reactors.

Dry reactors. In the closed distributors by voltage to 35 kV inclusively are applied dry air-cooled reactors. In the Soviet Union use extensively the concrete reactors, which are characterized by large simplicity of construction/design, sufficiently high reliability the works and comparatively small cost/value (Fig. 8-14).

The winding of 1 concrete reactor is performed of the flexible stranded copper or aluminum wire, isolated/insulated by several layers of the cable paper and covered with cotton braid/cover. On special framework/body is placed the winding of reactor in several horizontal and vertical series/rows, after which ast concrete

columns 2, which use for the attachment of the turns of reactor. After the solidification of concrete the coil of reactor thoroughly is dried in vacuum, they saturate with sludges (or drying oil) and then they cover/coat with varnish how is prevented/warned moistening concrete which is very hygroscopic.

With course through the reactor of short-circuit current when concrete strongly is heated, the moisture, which penetrated in concrete, evaporates and here it is condensed, as a result of which the surface of concrete is covered/coated with moisture. If the surface of concrete, furthermore, it is covered any carrying out in presence moisture with dust, then are possible breakdowns between turns and formation of arc, which can lead not only to the decomposition of the coil of reactor, but also to interphase short circuit. This all the more possible since with course through the reactor of short-circuit current the large part of the line voltage lies down on reactor. Therefore in operation it is necessary to follow the state of the varnish deposit of reactor and its cleanliness.

The locations in which are installed the reactors, must be ventilated well, and the maximum temperature in them must not exceed +35°C. The oscillations/vibrations of the temperature in location must not be such sharp that would be observed coating reactors with

hoarfrost, dew, etc.

The coils of concrete reactors insulate from the earth/ground with the aid of several stand-off insulators 3. The three-phase assembly of reactor consists of three coils, adjusted in horizontal plane by series/row or in vertical plane one on another. In the latter case of the coil of reactor they insulate from each other also with the aid of stand-off insulators 4.

During vertical installaton the directon of the windings of the coils average/mean phase C (Fig. 8-14) take by reverse in comparison with direction of the coils of upper and lower phases. Is done this, so that with the course on two adjacent coils of two-phase impact short-circuit current coils would be attracted/tightened, but not repulsed as this would be in identical direction of all coils (more easily fulfill the reliable attachment of coils). Therefore during mounting or after repair it is not possible the coil of the average/mean phase C to station of phases H and B. It is not possible to change also the direction of power supply to the coil of any phase.

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Main disadvantages in the concrete reactors - large weight and sufficiently considerable overall sizes. For example, the three-phase assembly of reactor to voltage 10 kV, rated current 400 A also resistor/resistance to 5o/o weighs 3x723=2,169 kg.

Analogous construction/design have dual concrete reactors.

In the closed locations and with a good drift/care concrete reactors work completely reliably.

Technical specifications of concrete reactors with the copper winding of the type RB and an aluminum winding of the type RBA to the nominal voltages 6 and 10 kV of the production of Soviet plants are given in table P-7.

Second type of dry air-cooled reactors - reactors of composite construction/design with porcelain, asbestos-concrete or wood packing between the series/rows of turns. The coil of the reactor of composite construction/design has upper and lower cover plates from

insulation and braces itself by through bolts. These reactors are characterized by the complexity of construction/design, relatively larger cost/value, also, in a number of cases by the smaller reliability of operation in comparison with concrete reactors (cast construction/design). The latter is explained by the fact that with course through the reactor of the impact current between its turns appear the forces of interaction, which usually lead to loosening of coil, in consequence of which are possible the precipitation of separators, insulation failure and closing/shorting between turns, which lead to the complete destruction of the coil.

The group of the dry reactors of composite construction/design includes the wooden reactors (type RD), intended for the closed installations by voltage to 10 kV with currents not more than 100 A. Advantages of these reactors - light weight, small sizes/dimensions and cost/value. In comparison with concrete ones wooden reactors are less reliable and therefore they are encountered on the noncritical installations of small power.

With installation of dry reactors in distributors it is necessary to observe the indicated by plant assembling distances of steel constructions/designs and reinforced concrete parts of the building (see Vol. 2, chapter 8). With the nonfulfillment of these requirements is feasible the dangerous heating of steel constructions

and steel armature of reinforced concrete by the currents, induced in them by the magnetic flux of the reactor; furthermore, the nearness of steel constructions/designs causes the additional losses of electric power.

Oil reactors apply in the open installations of all voltages, and also in installations by voltage above 35 kV, when dry reactors are not applied.

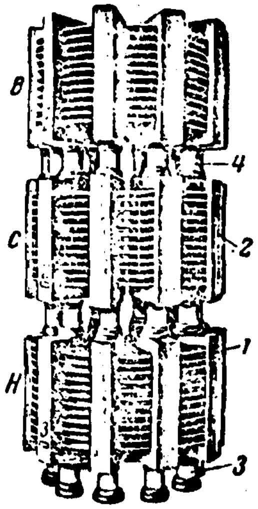
Oil reactors can have single-phase and three-phase performances. In the first case one coil, and the second - three coils are placed in the steel tank, flooded by transformer oil. Windings are performed from the copper conductors, isolated/insulated by the cable paper and packed to framework/body from insulation. The ends/leads of the coils are derived/concluded outside through passage porcelain insulators on the cover/cap of reactor.

The construction/design of the tanks of oil reactors in essence the same as the power transformers (see Chapter 23); therefore in appearance they very resemble power transformers.

If we do not take special measures, then the magnetic flux of oil reactor will be closed through the walls of the tank which in this case strongly is heated. For eliminating this are applied

electromagnetic screens or magnetic shunts.

In the first case on the internal surface of steel tank they fasten the circular copper screen, which appears as secondary winding of reactor (Fig. 8-15).



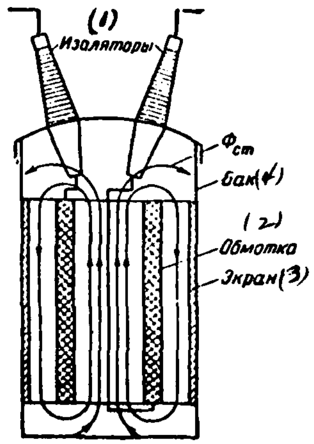


Fig. 8-14. Concrete reactor RB-6-200-6 on 6 kV, 200 A also nominal relative resistor/resistance to 6o/o.

Fig. 8-15. Schematic of reactor with oil cooling and

by circular copper screen.

Key: (1). Insulators. (2). Winding. (3). Screen. (4). Tank.

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In this screen are induced the currents, which create the magnetic flux which in the walls of tank is directed against the magnetic flux of coil of reactor. As a result through the walls of tank is closed

comparatively small resulting magnetic flux Φ_{CT}, in view of which tank is heated insignificantly.

In the second case on the internal surface of steel tank fasten the steel packets: is created seemingly artificial magnetic circuit with the reluctance, considerably smaller than the resistor/resistance of the walls of tank. Therefore the magnetic flux of reactor in essence is closed not through the walls of tank, but on magnetic shunt. For decreasing the hysteresis losses the shunt is performed made of transformer steel of high quality, while for decreasing the eddy current losses its they collect/compose from the thin ones, isolated/insulated from each other of steel sheets.

Oil reactors considerably more expensive than dry reactors, but in comparison with the latter they possess the series/row of essential advantages. They are reliably shielded from incidence/impingement into the winding of dust, moisture and any kind of extraneous o bject, and, furthermore, it is possible to establish/install them in any distance from steel and reinforced concrete constructions and in the open installations.

Soviet plants manufacture oil reactors with electromagnetic screens for the external installations: three-phase to voltage 35 kV (type RTMT-35) and single-phase to voltages 110 and 154 kV (types RSMO-110 and RSMO-154).

Chapter Nine.

INSULATORS.

9-1. General information.

Insulators serve for the attachment of current-carrying parts and their isolation from the earth/ground and other parts of the installation, which are located under another potential. Therefore insulators must possess sufficient electrical and mechanical strength, they must be heat-resistant and not fear dampness.

Distinguish insulators station-type, instrument rooms and linear.

Station-type insulators are applied for attachment and insulation of busbars in the distributor devices/equipment of electrical stations and substations. They are subdivided into supporting/reference ones and passage ones.

Wall entrance insulators are installed with the passage of the busbars through walls and overlaps indoors, and also during their conclusion/output from buildings.

The apparatus insulators, which use for the attachment of the current-carrying parts of the apparatuses, can have also a form of supporting/reference ones or passage. The latter apply for the conclusion/output of current-carrying parts from the apparatuses, equipped with enclosed casings, from oil breakers, power transformers, etc. In some apparatuses the insulators have a form of rods, thrusts/rods, levers, etc.

Linear insulators, serving for the attachment of the wires of the air electric power lines and busbars of the open distributors, are subdivided into bolt ones and suspension ones.

Station-type and line insulators are manufactured from porcelain as the material, which most completely corresponds to requirements indicated above. Apparatus insulators also in the majority of the cases are manufactured from porcelain.

Insulators can be manufactured also from the annealed glass, which possesses good electrical insulating properties and high thermal and chemical stability. Linear and apparatus insulators of glass have somewhat smaller overall sizes and considerably smaller weight and cost/value in comparison with porcelain ones. From glass

it is possible to manufacture linear and apparatus insulators to all voltages, switching on suspension insulators to high voltages 400-500 kV. Within the next few years Soviet plants must master the mass production of glass linear and apparatus insulators to all voltages.

From bakelite, Textolite, tree/wood and other similar to them materials are manufactured some parts of apparatuses, which are located within the jackets, flooded by insulating oil, and more rarely the parts, which work in air (only in apparatuses for internal installation).

For the attachment of insulator on support (steel construction/design, wall, etc.), and also for attachment to the insulator of busbars or current-carrying parts of the apparatuses it has metal insert/reinforcement, i.e., the metallic parts, attached on porcelain.

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In station-type insulators armature is secured on porcelain with the aid of the various kinds of the resin cements. In apparatus insulators apply also mechanical attachment the armatures on porcelain.

The porcelain housing of insulators from external surface is covered/coated with glaze for the purpose of an improvement in the electrical and mechanical qualities of insulator.

Depending on kind of installation distinguish station-type insulators for internal and external installations. The latter have the structural/design forms, which ensure their reliable work in the rain and in contaminated with dust state. In the installations, subjected to intensive contamination or action of harmful for insulation gases and evaporations, sometimes are applied the insulators of special constructions.

The mechanical strength of station-type insulators must be such that they would maintain/withstand with the specific safety factor the greatest electrodynamic efforts/forces, appearing with course on the busbars of impact short-circuit current (mechanical load in normal mode was small, since it is determined in essence by the weight of busbars).

Depending on mechanical strength insulators to one and the same voltage they manufacture different sizes/dimensions and subdivide into groups (A,B,C, D, E, or I, II, III). The mechanical strength of the insulator of each group is characterized the determined by value destructive mechanical load, by which is understood this smoothly

accompanying load on insulator in the plane of cap/hood and it is perpendicular to the axis of insulator with which can begin its partial or full/total/complete destruction. Permissible load to insulator is accepted as the equal to 60o/o of that destroying (characteristics of station-type insulators are given in table P-9).

Insulators one and the same of group, but to different nominal voltages, differ from each other in terms of the active height of porcelain (h in Fig. 9-1), while the insulators of different groups to one and the same voltage - by a diameter of porcelain housing.

Feedthrough insulators are additionally distinguished by the section of the current-carrying rods, designed for specific rated currents (see table P-9).

Soviet plants manufacture insulators to all voltages to 500 kV inclusively.

9-2. Stand-off insulators.

Stand-off insulators for internal installations by voltage are higher than 1000 V. Widest application in Soviet installations by voltage 6-35 kV inclusively have the stand-off insulators of series O (types OA, OB, OC, OD), characteristic feature which is the external

seal of armature (Fig. 9-1a): cast iron collar 2 and cast iron cap/hood 3 are secured on porcelain housing 1 with the aid of cement cement 4.

Insulators of types OA and OB have circular (Fig. 9-1a) or oval collars 2, while those of types OC and OD - square.

With circular flange the insulator is fastened to metal construction with one bolt which is screwed into central threaded/cut opening/aperture in collar 2. In oval collars there are two openings, while in square ones - four, that use for the attachment of insulator to support by respectively two or four through bolts.

In cap/hood 3 are threaded/cut openings/apertures for the attachment of current-carrying parts.

At present Soviet plants manufacture also stand-off insulators to the voltages 6-20 kV of new construction/design - small/miniature insulators of series OM (types OMA, OMB, OMC, OMD, OME).

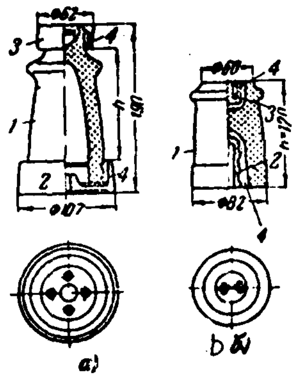

Fig. 9-1. Stand-off insulators to voltage 10 kV for internal installation. a) type OA-10 with outside seal of armature (old construction/design); b) the type OMA-10 small/miniature with the internal seal of armature (new construction/design).

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The characteristic feature of these insulators (Fig. 9-1b) is the internal seal of the armature, which consists of two nipples 2 and 3; the latter are secured in cement mortar 4 in deepenings in the end-type parts of the porcelain housing 1 of insulator [L 9-1].

Upper nipple 3 has two threaded/cut openings/apertures for the attachment of current-carrying parts, and lower nipple 2 - one or two openings/apertures with cutting for the attachment of insulator on metal construction.

The internal seal of armature decreased the height of insulators approximately/exemplarily on 40o/o at the same active height of porcelain h, which is evident from the comparison of outlines a and b in Fig. 9-1. The total weight of insulators decreased approximately/exemplarily 2 times mainly due to the reduction of the weight of armature and cement. Decreased the cost/value of insulators.

In the insulators of series OM for the reliable cohesion/coupling of cement mortar with the porcelain housing of insulator during the glazing of porcelain to the surface of end-type deepenings will be deposited porcelain grit. So that there would not be the rotations, nipples notched and edges/fins.

Stand-off insulators for external installations. For external installations Soviet plants manufacture the stand-off insulators of bolt and rod types. Fig. 9-2 gives bolt stand-off insulator to voltage 35 kV of the type ShT-35, which consists of two porcelain elements/cells 1 and 2, cast iron cap/hood 3 and cast iron stub with collar 4, fastened between themselves resin cement 5. Insulators on 35 kV of the type IShD-35 have three porcelain elements/cells, while insulators on by 6 and 10 kV of types ShN-6 and ShN-10 - only one.

The sizes/dimensions of pin insulators and the developed surface

of porcelain elements/cells provide their reliable work in the open distributors.

For external installations 110 kV and above are applied the columns of pin insulators, assembled from stand-off insulators 35 kV: on 110 kV - of three insulators of the type ShT-35, on 220 kV - of five insulators of the type IShD-35. A similar column of pin insulators to voltage 220 kV it is possible to see in Fig. 16-7 part 5).

In contrast to bolt ones, rod stand-off insulators are simpler structurally/constructurally, they have smaller diameter, it is cheaper and they are more reliable; therefore in recent years they find an increasing use.

Soviet plants manufacture stick insulators to all voltages to 110 kV inclusively. In the form of an example Fig. 9-3 shows rod stand-off insulator to voltage 35 kV of the type SO-35. In the new constructions/designs of disconnectors for external installation are applied stick insulators of types ST-35, ST-110, . (Fig. 16-8).

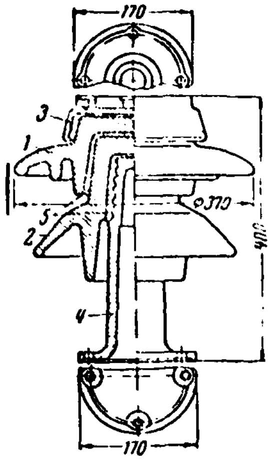
To especially high voltages are applied composite/compound stick insulators, as this it is possible to see in Fig. 16-9, where each stand-off insulator of disconnector to voltage 400 kV is comprised of

struts on eight stick insulators in each. To insulator is attached the form of trihedral pyramid for an increase in the mechanical strength.

9.3. Feedthrough insulators.

Feedthrough insulators for internal installations Soviet plants manufacture three types: 1) with the current-carrying cruxes of the rectangular cross section; 2) busbar/tire and 3) with the current-carrying cruxes of round cross-section.

Feedthrough (wall entrance) insulators with the current-carrying cruxes of rectangular cross section manufacture to voltages 6 and 10 kV and rated currents 200-1500 A (type PA and PB). This insulator (Fig. 9-4) consists of gently porcelain housing 1, on middle cylindrical part of which is attached on the resin cement oval collar 2 with two openings/apertures 3, which serves for the attachment of insulator in support by two bolts.



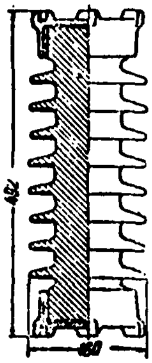


Fig. 9-2. Bolt stand-off insulator of the type ShT-35 on 35 kV.

Fig. 9-3. Rod stand-off insulator of type SO-35 on 35 kV for external installation.

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Within porcelain housing passes the current-carrying busbar 5 rectangular cross sections, attached with the aid of two metallic washers 4 with the rectangular openings/apertures, which correspond to the section of busbar. Washers enter into deepenings in the ends/faces of the porcelain housing of insulator.

At the ends/leads of the current-carrying busbar are openings/apertures for connection to it with the aid of the bolts of

the busbars of distributor or current-carrying parts of the apparatus.

Use/application of the flat/plane current-carrying busbars in wall entrance insulators 6-10 kV gives essential metal savings, since permissible load on flat/plane busbars is more than to circular ones, simplifies both the construction/design of insulator and the connection to it of the flat/plane busbars which are applied in distributors 6-10 kV.

In installations 6-10 kV round rods have only wall entrance insulators of the type PV. Furthermore, round rods are applied also in wall entrance insulators of some apparatuses to voltages 6-20 kV.

In installations with voltage to 20 kV inclusively with the currents of load more than 600 A use extensively busbar/tire type wall entrance insulators (Fig. 9-5), which are supplied by plants without current-carrying parts (type IPSh). During the mounting through such insulators pass the busbars by which is assembled the distributor. Through the insulator can be passed one busbar of rectangular cross section or packet, which consists of several flat/plane busbars (see § 10-2 and Fig. 10-2).

Busbar/tire insulators have caps/hoods of 3 special constructions/designs. On each cap/hood with the aid of two bolts are secured two steel planks 4 with rectangular grooves for the passage of busbars. The sizes/dimensions of these grooves are determined by the dimensions and number of busbars, passed through the insulator. During input into insulator and output from it of the packet of the busbars between them are established/installed the separators (spacer) by the thickness, equal to the thickness of busbars in the packet (are used the clippings of the busbars being assembled).

Wall entrance insulators to voltage 35 kV have the round

current-carrying rods.

Weakest in electrical sense place of partition insulator is its middle part - between the current-carrying rod and the grounded collar. Therefore in wall entrance insulators to voltage 35 kV for the purpose of increase of dielectric strength of insulator the current-carrying rod within porcelain housing they additionally insulate by the Bakelite paper.

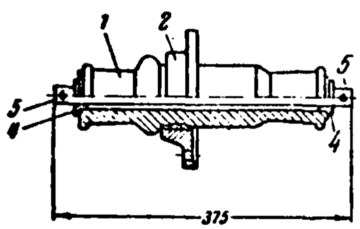
The collars of wall entrance insulators to rated currents less than 1500 A and the caps/hoods of insulators to currents of less than 1000 A manufacture from gray cast iron, and with large rated currents - from non-magnetic cast iron (or silumin), since with their fulfillment from gray cast iron they in such high currents are excessively heated by eddy currents, also, as a result of hysteresis.

For the same purposes the cast iron collars of some wall entrance insulators are fulfilled of two halves, bolted (Fig. 9-6): air gap between halves of collar considerably increases reluctance and, therefore, reduces induction in the parts of collar and heating by their eddy currents, also, as a result of hysteresis.

Because of the small air gap between them insignificantly are in exactly the same manner heated U-shaped steel planks by 4 on the

caps/hoods of passage busbar/tire insulators (Fig. 9-5).

Wall entrance insulators for external installations (linear conclusion/output) to voltages 6-35 kV Soviet plants manufacture to rated currents 400-4000 A (types PNB and PNV).



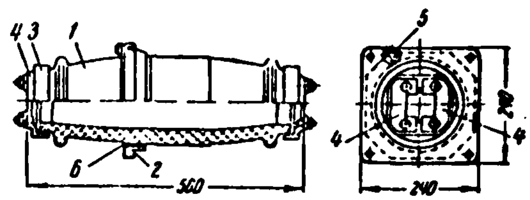


Fig. 9-4. Wall entrance insulator of the type PA 6/400 on 6 kV, 400 A for internal installation.

Fig. 9-5. Passage busbar/tire insulator of type IPSh-1-10 on 10 kV ($F_{\text{разр}} = 2000$ кГ). 1 - porcelain housing; 2 - collar; 3 - cap/hood; 4 - steel planks; 5 - bolt for grounding; 6 - cementing adhesive.

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All these insulators have the round current-carrying rods, except insulators to 20 kV and rated currents 2000-4000 A, in which as the current-carrying rods are applied the packets of two copper rectangular busbars.

The special feature/peculiarity of linear conclusion/output is the different fulfillment of the external and internal parts of the porcelain housing (Fig. 9-6). The external part, arranged/located out of building or outside of apparatus, has more developed surface (series/row of edges/fins) and large sizes/dimensions.

Fig. 9-6 in the form of an example gives linear conclusion/output on 35 kV and 600 A type PNB-35/600. Current-carrying copper rod 4, which has at ends/leads thread, is passed within porcelain housing 1 and it is secured in caps/hoods 2 by screwed to it centering washers 5 with the female thread. For preventing the incidence/impingement of moisture inside porcelain housing from the face of the insulator above the washer is multiplexing from the saturated cardboard, washer itself is fastened to cap/hood with screws/propellers, and the current-carrying rod in the place of contact with washer is soldered.

In some outfits of 35 kV for external installation, having a housing, filled with insulation oil, there are applied bakelite insulators, equipped on the internal part with porcelain cover, internal cavity of which is filled with insulation oil for protection of bakelite from moisture (Fig. 17-14).

Station-type and apparatus wall entrance insulators and linear conclusion/output by voltage 110 kV and higher have more complicated construction/design. Their current-carrying rods are isolated/insulated by the Bakelite paper, superimposed in the form of several concentric cylinders. Porcelain housing consists of two

halves, connected by metallic collars, which considerably simplifies and reduces the cost of the production of insulators. The internal cavity of this insulator is poured by insulating (transformer) oil, which increases dielectric strength of insulator and improving its cooling. In upper part the insulator is supplied with glass container, that performs the role of expander and making it possible to monitor the oil level in insulator. The oil-filled conclusion/output can have the separate established/installed on wall (higher than the insulator) oil tanks, connected by an oil line with an internal insulating cavity.

For the uniform distribution of voltage in the Bakelite insulation surrounding the current-conducting rod, which raises the break-down voltage of the insulation, insulators for a break-down voltage of 110 kV or higher are often made as the condenser/capacitor type. In these insulators between the layers of bakelite run the tinfoil separators, which perform the role of capacitor plates. This insulation is as if a series/row of the series-connected capacitors/condensers, moreover the first facing is the current-carrying rod. Latter/last facing is grounded (it is connected to the grounded collar of insulator). Condenser/capacitor type insulators are supplied oil breakers, and sometimes power transformers by voltage are 110 kV and are higher (Fig. 17-4 and 17-8).

9-4. Line insulators.

Linear pin insulators are applied for the attachment of the wires of the small outdoor substations by voltage to 35 kV inclusively. Fig. 9-7 gives the outline of pin insulator 35 kV of the

type ShD-35. Insulator consists of two porcelain elements/cells 1 and 2, connected by resin cement 3. Steel pin on outline is not shown.

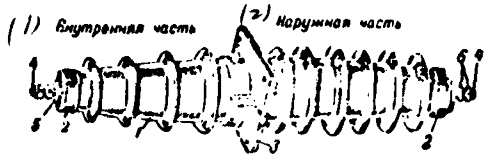

Fig. 9-6. Wall entrance insulator for external installations (linear **conclusion/output) of the type PNB-35/600 on 35 kV, 600 A.**
1 - porcelain housing; 2 - cap; 3- detachable flange; 4 - current-conducting rod; 5 - centering screw; 6 - bolt for attaching conductive busses.
Key: (1). Internal part. (2). External part.

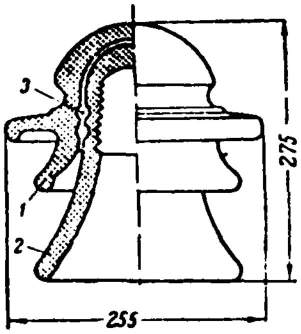

Fig. 9-7. Linear pin insulator of type ShD-35 **on** 35 **kV.**

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Suspension insulators apply in open type installations by **voltage 35 kV even above. Fig. 9-8 shows the very** propagated **suspension insulator of the type P-4.5 for greatest** working load 4.5 **t.**

From separate suspension insulators comprise the supporting or

tightening string insulators. In the open distributors, as a rule, are applied tightening garlands (Fig. 9-9).

A number of insulators in garland for normal type installations is applied: 35 kV - 3-4; 110 kV - 6-7; 220 kV - 12-14; 400 kV - 22. For devices subjected to intense pollution (primings from boiler and other industrial enterprises), the number of insulators per garland increases 1-2 times; in the presence of heavy atmospheric pollution garlands are made from specially-designed suspended insulators with a larger surface area.

Sometimes suspension insulators are applied also in the open installations by voltage 6-20 kV. In this case sufficiently one insulator.

With the assembly of insulators the butt end of rod 3 (Fig. 9-8) one insulator introduces through the gash into cap 2 of another insulator and they cut off it there with the aid of the special lock, which has the form of plate.

Upper insulator 1 they connect with thimble 2 (Fig. 9-9), used for attachment garland on support. In the pole arms of supports are installed the special thimbles or the hangers, with which engage the thimbles of garland. The rod of lower insulator 3 they connect with lug 4, to which is fastened/strengthened tightening terminal/gripper 5, which holds wire 6.

In installations by voltage 110 kV instead of the garland of six suspension insulators of the type P-4.5 it is possible to apply one

suspension stick insulator of the type SP-110 (Fig. 9-10). These insulators more easily are cheaper than the garlands of suspension insulators.

In more detail about linear insulators see [L 7-1 and 9-2].

9-5. Selection of insulators.

All insulators select on voltage, kind of installations and permissible mechanical load. Wall entrance insulators additionally are selected on rated current.

Insulators reliably work with the voltage, which exceeds their nominal voltage; on 15% - insulators to 35 kV inclusively and to 10% - insulators 110 and 220 kV. Since the maximum working voltage of electrical installations exceeds their nominal voltage by not more than 5-10% (see §3-1) when selecting insulators for a voltage it is sufficient to observe the condition:

$$U_{\text{из.ном}} \geqslant U_{\text{уст.ном}}, \qquad (9\text{-}1)$$

where $U_{\text{из.ном}}$ - nominal voltage of the insulator; $U_{\text{уст.ном}}$ - nominal voltage of the installation, numerically equal to the nominal voltage of the network supplied from this installation (see Ch. 3).

Selection on the kind of installation bears in mind the selection of insulators for internal or external installation.

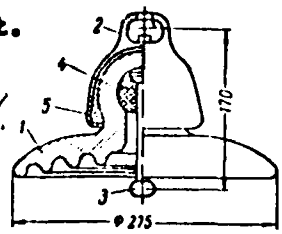
When selecting of insulators on the permissible mechanical load (selection of the group of insulater) must be observed the condition:

$$F_{\text{расч}} \leqslant 0{,}6 F_{\text{разр}}, \qquad (9\text{-}2)$$

where $F_{\text{расч}}$ - greatest design load on insulator with three-phase impact short-circuit current; $F_{\text{разр}}$ - breaking load on the catalog; 0.6 - safety factor.

Fig. 9-8. Suspension insulator of the type P-4.5 for greatest working load 4.5 t. 1 - porcelain housing; 2 - cap from malleable cast iron zinc-coated, 3 - steel rod (stub, pestle); 4 - lead-antimony alloy; 5 - the resin cement.

Fig. 9.8.



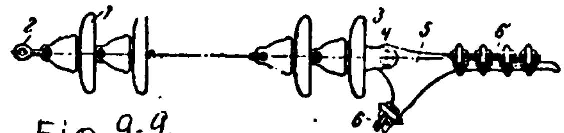


Fig. 9-9.

Fig. 9-9. Tightening of link of insulators to voltage 110 kV.

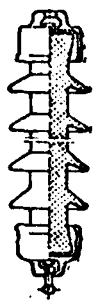


Fig. 9-10. Suspension stick insulator of type SP-110 on 110 kV.

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In § 7-1 it was indicated that during the location of phases in one plane and during three-phase short circuit under severe conditions is located the busbar of average/mean phase. With the identical flights/spans between the axes of stand-off insulators (Fig. 9-11) in each flight/span on the busbar of average/mean phase operates force $F^{(3)}$, determined according to formula (7-3). The same force is applied

to average/mean insulators 2 and 3 (reaction to the support of continuous beam/gully). It is obvious that to outer stand-off insulator 1 and cap/hood of wall entrance insulator 4 is applied only the half $F^{(3)}$, i.e., $\frac{F^{(3)}}{2}$.

From the aforesaid it follows that during checking of insulators to mechanical strength according to formula (9-2) one should accept: for the stand-off insulators

$$F_{расч} = F^{(3)}; \qquad (9\text{-}3)$$

for wall entrance insulators

$$F_{расч} = 0,5F^{(3)}. \qquad (9\text{-}4)$$

In the case of different flights/spans on both sides of the stand-off insulator

$$F_{расч} = \frac{F_1^{(3)} + F_2^{(3)}}{2},$$

where $F_1^{(3)}$ and $F_2^{(3)}$ - force of interaction in adjacent flights/spans.

Since $F_{разр}$ is determined for the case of the application/appendix of the bending force directly to the cap/hood of insulator, then in the location of busbars on stand-off insulator to edge/fin and force direction perpendicular to the axis of the insulator (see Fig. 9-11) one should decrease the permissible load or which is equivalent, design load to increase in accordance with an increase in the arm of application of force, i.e., one should accept

$$F_{расч} = F^{(3)} \frac{H}{H_{из}}, \qquad (9\text{-}5)$$

where $H_{из}$ - height of the stand-off insulator; H - distance from the foundation of insulator to the horizontal axis of the busbar; usually accept

$$H = H_{из} + b + \frac{h}{2},$$

where b is considered the thickness of the lower plate of bus-holder (see Fig. 10-7).

When selecting of wall entrance insulator on rated current must be observed the condition (see also indications in § 21-1)

$$I_{из.ном} \geq I_{н.макс}, \qquad (9\text{-}6)$$

where $I_{н.макс}$ - a maximum prolonged current of the load of circuit in which is installed wall entrance insulator.

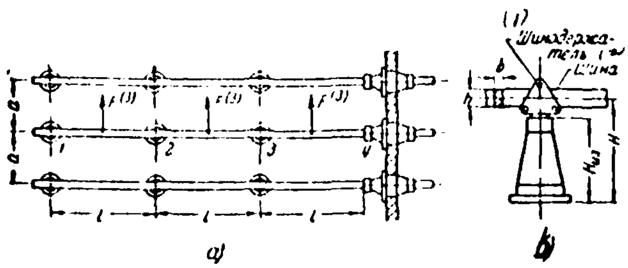

Fig. 9-11. To the determination of the calculated mechanical load of supporting and wall entrance insulators.

Key: (1). Bus-holder. (2). Busbar.

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Chapter Ten.

BUSBARS OF DISTRIBUTORS.

10-1. Material and form of section of busbars.

In the closed and open distributors of all voltages of electrical stations and substations the collecting mains and all connections between apparatuses in the separate circuits (see Fig. 3-2), and frequently also the connections of generators, synchronous condensers, step-up and step-down transformers to the corresponding distributors perform by bare (not insulated) conductors of rectangular, round and tubular sections and by flexible stranded wires, fastened/strengthened to insulators. Further all these conductors let us call busbars.

Material of busbars. In distributors are applied copper, aluminum and steel busbars. Copper is one of the best conductors of electric current. It possesses smaller electrical resistance in comparison with aluminum and steel with sufficiently large mechanical strength; therefore the section of copper busbars is obtained

smallest, which is especially substantial in installations with the high values of currents.

Copper resists well the effect of the majority of chemical reagents, which are found in air; therefore copper busbars should be applied when the closed or open distributor is installed near marine coast, saline lakes or chemical plants where as a result of corrosion is possible the decomposition of busbars from other metals (zone of the increased corrosion usually is counted in a radius of 5 km).

Aluminum possesses approximately/exemplarily 1.6-2 times high resistivity in comparison with copper; therefore with the same load and to identical permissible heating temperature the section of aluminum busbars is obtained large. In spite of this, by the weight of aluminum it is expended/consumed 2-2.5 times less, since it more easily copper 3.3 times. As a result aluminum busbars prove to be more advantageous than copper ones. Therefore in the closed and open distributors one should use extensively aluminum busbars.

Steel busbars possess considerable specific resistor/resistance (approximately/exemplarily 7 times more than copper ones). In alternating current are essential the losses in steel busbars, caused by hysteresis and eddy currents. At the same time steel busbars are cheap.

Steel busbars are commonly used in low-power installations by voltage higher than 1000 V, and also in group and switchboards and to that similar devices/equipment of alternating current by voltage to 1000 V with operating current usually to 200-300 A also it is rare with large ones. In the installations of direct current are applied steel busbars, also, to large operating currents.

Form of the section of busbars. In devices with voltage of up to 35 kV inclusive, busses with a rectangular cross section, (Fig. 10-2a) which are more economical than round busses with a solid cross section, are used. In identical cross-sectional area rectangular busbars better are cooled as a result of larger surface of cooling. Futhermore, with alternating current the electrical resistance of the circular busbars is greater than rectangular ones of the same sectional area, as a result of surface effect - nonuniform alternating-current distribution according to the section of busbar. With alternating current the greatest current density is observed on the surface of conductor, and smallest - in the middle of conductor. As a result of entire this the let-go current of load on rectangular busbars is more than to circular ones (at identical sectional area and heating temperature).

For the purpose of the best cooling and decrease of the effect of surface effect it is expedient to apply the rectangular busbars of small thickness. Based on this, and also taking into account

mechanical strength, copper and aluminum busbars usually have relationship/ratio of sides 1/5-1/12 (greatest busbar 10•120=1200 mm²). Steel busbars in the installations of alternating current apply not thicker than 4 mm.

In installations voltage it is above 35 kV with the fulfillment of busbar/tire constructions/designs necessary to consider the phenomenon of corona.

It is known that there is an electrical field around the wire, the intensity of which depends on the voltage of the installation and the distance between phases. With an increase in the voltage and with the decrease of the distance between phases the electric intensity increases. The greatest electric intensity is observed near the surface of the wires; in proportion to distance from wire the electric intensity rapidly decreases. If electric intensity near the surface of wire exceeds the value of dielectric strength of air (approximately/exemplarily 21.1 kV/cm), then around wire occurs the intense ionization of air and appears the violet glow, called the corona (it is well visible in darkness).

Dielectric strength of air depends on weather conditions: humidity, temperature, barometric pressure. In damp/crude weather the corona is more strong, rather than in dry weather.

The corona of busbars is very undesirable, since the intense

ionization of air decreases its dielectric strength, which facilitates flashing over and breakdown between phases, especially if the surface of insulation is contaminated. In the region of corona occur the chemical reactions, which are accompanied by the formation of ozone and nitrogen oxides. Ozone intensely oxidizes the metal constructions of distributor.

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Nitrogen oxides form with water the nitric acid, which destructively operates on organic insulation and metals. The corona of busbars, which is accompanied by characteristic noise and crackle, impedes the functional check of equipment by crosstalk by its operating personnel. Light crackles with sparking in the loosely connected contacts and during the incipient breakdown or overlap in apparatuses, the jarring humming as a result of leakages/loosenesses in the magnetic system of transformers and so forth is difficult to hear, if the busbars of distributor display corona. However, by the timely detection of the phenomena indicated it is possible to avoid the development of damage and to warn/prevent emergency.

With the corona of busbars occurs certain loss of electric power [L 7-1]. However, as a result of comparatively small length of busbars of distributors, these losses do not have vital importance.

Intense corona is observed in installations by the voltage of above 35 kV; therefore in Soviet installations by voltage 110 kV and above are applied either tubular busbars or stranded wires, the same as on electric power lines, since with the given voltages of installation and the distance between phases it is possible by an increase in the diameter of tubular busbar or stranded wire to so decrease the strength of field on their surface, that they will in no way display corona (see § 10-2).

Tubular busbars fasten on bolt or rod stand-off insulators (rigid set of tires). Are applied aluminum, steel and copper tubes.

Stranded wires fasten on suspension insulators (flexible set of tires). Normally are applied steel-aluminum less frequently thinner than copper stranded wires. With the same wires is made the flexible set of busbars of the open distributors 35 kV.

In the installations of very high voltages (220 kV it is above), where operating currents are comparatively small, and in the condition of inadmissibility of corona the diameter of wire must be considerable, it is expedient to apply for the purpose of metal savings flexible hollow copper wires (brand MP).

In distributors normally are applied the bare uninsulated busbars, which is explained: 1) by the smaller cost/value of the bare busbars; 2) by simplicity of their mounting even 3) by the larger permissible load, which gives savings of metal. Insulated busbars apply only in those distributors of the special constructions/designs where with the abbreviated/reduced overall sizes it cannot be maintained the necessary distances between bare busbars.

10-2. Selection of busbars.

The section of the busbars of distributors select by economic current density and check against maximum prolonged current loads, on corona and on thermal resistance and mechanical strength during short circuits.

Selection of the section of busbars on economic current density. With flows on the busbars of the current of load in which depends on the strength of current of load and section of busbars, i.e., their resistor/resistance ($\Delta A=3I^2rt$, considering that for time t the load of busbars it remains constant/invariable).

With one and the same current of load the greater the section of

busbars, the less the energy loss in them and, consequently, also the cost/value of lost electric power (curve 1 in Fig. 10-1). On the other hand, an increase in the section of busbars leads to an increase in the cost/value of busbar/tire construction/design, and consequently, to an increase in the expenditures for repair and depreciation allowances of the busbar/tire construction/design which are proportional to its cost/value (curve 2 in Fig. 10-1; depreciation allowance they are the deductions for the fund for the restoration/reduction cf construction/design).

Storing/adding up the ordinates of the curves of 1 and 2, we obtain curved 3, which characterizes variable component of total operating costs in dependence on the section of busbars. As is evident, with certain section of busbars $s_{эк}$, which can be named/called economic, the operating costs prove to be smallest.

With an increase in the average annual load of the busbars (more uniform annual graph/curve, larger value $T_{макс}$) of the loss of electric power in busbars increase (with the same section of busbars), and consequently, increase and the cost/value of the lost energy (dotted curve 1'). As a result of this the economic section of busbars is already somewhat larger section $s'_{эк}$.

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From of the curves of Fig. 10-1 it is evident that with the sections of busbars, somewhat smaller $s_{эк}$, initial costs of busbar/tire construction/design decrease considerably more rapid, rather than increase annual operating costs. Therefore of the state considerations proves to be economically more advantageous to accept the section of busbars somewhat smaller $s_{эк}$, providing thereby the considerable decrease of the expenditures of metal and resources for the installation of busbar/tire construction/design with a very small increase in the annual operating costs. The freeing resources and metal can be used for expanding the energy construction.

Taking into account all this, technical control of MES of the USSR established/installed led in PUE [L 3-6] the so-called maximum economic current densities $j_{эк}$ for bare wires of busbars (tables 10-1), using which should be determined the sections of wires and busbars, used for the set of tires of the distributors of all voltages:

$$s = \frac{I_н}{j_{эк}}, \qquad (10\text{-}1)$$

where $I_н$ - current of the greatest constant load of circuit in the normal mode of work (without taking into account the possible in operation overloadings of a circuit, and also increase of its load during emergencies and repairs).

The obtained condition (10-1) section they round off to nearest larger standard on table P-10. Selected thus section provides sufficient efficiency/cost-effectiveness of the operation of busbar/tire construction/design with a rationally possible savings of metal and resources to its installation.

The section of the collecting mains of the distributors of all voltages, and also busbars of temporary/time installations by economic current density does not select. The busbars indicated select on let-go current loads, as this shown below.

Checking the section of busbars to the maximum prolonged current of load (checking for heating in normal mode). With any possible in operation current of lcad the temperature of heating busbars must not exceed the specific value. According to the in force in the USSR norms the long permissible temperature of heating bare wires and busbars is accepted equal to 70°C, since at larger heating temperature is observed the intensive oxidation of the contact connections of busbars, which leads to a considerable increase in their contact resistance. The calculated temperature of air is accepted by 25°C. Under these conditions are determined the long let-go currents of load cn busbars and bare wires (tables P-10),

which must not be exceeded in the normal operation of installation.

From the aforesaid it follows that the section of busbar, determined according to economic current density, must be such so that with the maximum prolonged current of the load of that circuit, for which it is intended, the temperature of its heating would not exceed $\vartheta_{доп}$ =70°C. For this must be observed the condition:

$$I_{доп} \geqslant I_{н.макс}, \qquad (10\text{-}2)$$

where $I_{доп}$ - the long let-go current of load on busbar on table P-10; $I_{н.макс}$ - maximum prolonged current of the load of that circuit, for which is intended the busbar.

(1)

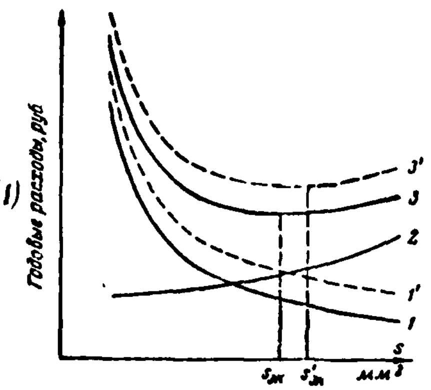

Fig. 10-1. Dependence of operating costs on the section of current-carrying part (busbar, cables).

Key: (1). Annual expenditures/consumptions, rub.

Table 10-1. Maximum economic current density of bare wires and busbars.

(1) Наименование проводников	(2) Предельная экономическая плотность тока $i_{эк}$, $а/мм^2$ (3) при продолжительности использования максимума нагрузки $T_{макс}$, ч		
	(4) свыше 1 000 (6) до 3 000	(4) свыше 3 000 (6) до 5 000	(4) свыше 5 000 (6) до 8 760
(5) Голые провода и шины			
а) медные	2,5	2,1	1,8
б) алюминиевые . . .	1,3	1,1	1,0

Key: (1). Designation of conductors. (2). Maximum economic current density $i_{эк}$, A/mm². (3) with the demand time of load peak $T_{макс}$, h. (4) it is more than. (5). Bare wires and busbars: a) copper; b) aluminum. (6) to.

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If condition (10-2) is not satisfied for the busbar, selected on economic current density, then should be selected the busbar of large section.

When under the conditions of operation is possible the prolonged overloading of circuit, for which is intended the busbar, current $I_{н.макс}$ should be determined taking into account this overloading. So, for the circuits of generators one should consider that the generators can long work with nominal power with the voltage, lowered/reduced to 5o/o against nominal, i.e., with the current of load 1.05 $I_{г.ном}$ (see Chapter 22); power transformers under certain conditions can long work with overloading to 30-40o/o (see Chapter 23), etc.

Collecting mains should be selected taking into account possible current distribution in them in different modes/conditions of the work of the installation: in normal mode, with cutoff/disconnection of one of generators or transformers, etc. On powerful/thick installations and at the considerable length of collecting mains for the purpose of metal savings it is possible to apply in different sections of the busbar of different sections (stepped busbar).

The rated currents of voltage transformers are negligibly small; therefore busbar to them it is possible to select circular, steel, by the diameter of 8-10 mm.

Table P-10-1-P-10.4 gives the long permissible loads with alternating current 50 Hz on the bare painted busbars of different material, form and sectional area.

The constant of the emission of the painted busbars is considerably more than not colored ones. So, if the constant of the emission of the not colored oxidized surface of copper band composes approximately/exemplarily 0.5, then for the painted surface of the same band the constant of emission comprises already about 0.9-0.95. Therefore the coloration of busbars improves their cooling by emission, as a result of which with the same permissible temperature of heating the let-go current of the load of the painted busbars on 12-15o/o more than not cclored busbars.

The permissible loads on busbars, with direct current somewhat greater than those given in table P-10 as a result of the absence of surface effect with direct current.

With the horizontal separator of rectangular busbars and during the location of them prone on support insulators (Fig. 10-3b) the

permissible load on table P-10.1 and P-10.2 must be reduced as a result of the worse cooling of the busbars: by 5o/o for busbars in bandwidth to 60 mm and by 8o/o for busbars in bandwidth of more than 60 mm.

With an increase in the section the permissible current density descends as a result of the worse cooling of the busbars of large sections, and with alternating current also because of the larger effect of surface effect.

For example, to aluminum busbar by section $40 \cdot 5 = 200$ mm² is allowed/assumed current 540 A at current density $540/200 = 2.7$ A/mm², and to aluminum busbar $100 \cdot 10 = 1000$ mm² is allowed/assumed current 1820 A, i.e., already $1820/1000 = 1.82$ A/mm². In the second case the metal is utilized more badly $2.7/1.82 \approx 1.5$ times.

On the same reasons to disadvantageously apply the busbars of large thickness.

For example, to aluminum busbar $60 \cdot 8 = 480$ mm², is allowed/assumed current by 1025 A, and to busbar $80 \cdot 6 = 480$ mm², i.e., the same section, but thinner, is allowed/assumed current 1150 A, which is approximately/exemplarily to 12o/o more.

With the significant magnitude of the operating currents, which exceed the let-go current of the band of the greatest section, they apply to phase several bands, collected/built in common packet and fastened together on stand-off insulators (Fig. 10-2b and c and Fig. 10-7b). The distance between bands in packet take by the equal to thickness one band, which is necessary for their cooling.

With an increase in the number of bands by phase the permissible load grows/rises proportional to a number of bands in packet, but it is considerably less as a result of the worse cooling of busbars in packet. Furthermore, with alternating current has high value the so-called proximity effect. Each band of packet is located in the alternating magnetic field of adjacent bands, in consequence of which is raised its effective resistance and, consequently, also heating with one and the same current.

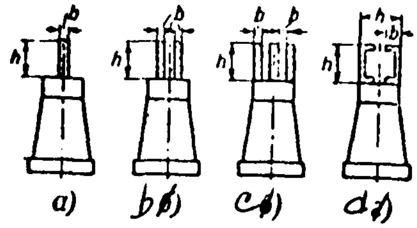

Fig. 10-2. Diagrams of busbar/tire constructions/designs. a - single-band busbar; b - packet of two bands; c - packet of three bands; d - packet of two box busbars.

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With a number of bands in packet more than two proximity effect lead to nonuniform current distribution in the bands of packet - in middle strips the current will be less than in extreme ones. So, with three bands in packet current in extreme bands will be on 40o/o, and in middle strip 20o/o of the total current of phase. Thus, current density in middle strips is considerably less than the current density in extreme bands. As a result of using the metal of busbars in packet it is considerably less in comparison with the use of a metal of the singly run bands.

For example, if one copper busbar by the size/dimension 100x10 of mm allows/assumes the current of load 2310 A (2.31 A/mm²), then the let-go current of packet from two the same bands composes 3610 A

(1.8 A/mm²) instead of 2•2310=4620 A, and packet of three bands 4650 A (1.55 A/mm²) instead of 3•2310=6930 A.

Therefore with alternating current it is better to apply not more than two, also, as an exception of three bands in packet. With the direct current when there is no proximity effect and current is distributed evenly between strips of packet, it is possible to apply packets with a large number of bands.

In the powerful/thick installations of alternating current with very larger operating currents should be applied the more economical busbar/tire constructions/designs, which ensure least possible effect of surface effect, proximity effect and best conditions for cooling.

By an increase in the distance between bands of the packet of flat busbars it is possible to somewhat reduce the effect of proximity effect and to improve cooling busbars, but attained in this case increase in the long let-go current is comparatively small with complication of the attachment of the packet of busbars on stand-off insulators. Incomparably more rational are the busbar/tire constructions/designs, made from two aluminum or copper box busbars of large cross section (Fig. 10-2d). Because of small effect of proximity effect and sufficient to good cooling the use of a metal of box busbars is obtained considerably better (table P-10.4) in

comparison with the packet of the rectangular busbars of the same overall section.

For example, if packet of four aluminum bands by size/dimension 120x10 mm by overall section 4800 mm² allows/assumes the current of load 4650 A (table P-10.1) or 0.97 A/mm², then two box aluminum busbars with the size/dimension of shelves 175 mm and 80 mm by overall section 2•2440=4880 mm² allow/assume current 6430 a (tables P-10.4) or 1.32 A/mm², i.e., it is more 1.36 times.

From box busbars are easily feasible busbar/tire constructions/designs to very large operating currents, to 10-12 kA and more.

Comparative calculations show that usually the already three-band packets of busbars it is profitable to replace by box busbars.

For example, for a circuit with $I_{н.макс}=4$ kA it is possible to select: packet of three aluminum bands 120x10 mm with s=3600 mm² and $I_{доп}=4100$ A or two box busbars with the size/dimension of bands 125 mm and 55 mm with s=2•1370=2740 mm² and $I_{доп}=4640$ A. With box busbars the section is less by 24o/o, but let-go current is more by 13o/o. The rationality of the use/application of box busbars does not cause

doubts.

The long let-go currents of load on the bare not colored wires, defined at a permissible temperature of their heating by 70°C and at temperature of air of 25°C, used both for aerial lines and for the set of tires of distributors, are given in table P-10.5.

If real temperature of air differs from calculated, equal to 25°C, then the permissible load of busbars and wires should be changed, taking into account correction factor $k_т$ in table P-11.6, in this case under the temperature of air both inside and outdoors should be understood mean temperature in 13 h of the hottest month. At the same time PUE [L 3-6] recommend the considering of these correction factors during the determination of the permissible load on leads of busbar only when the real temperature of air considerably differs from calculation of 25°C, namely: for regions of the extreme north, of the permafrost, tropics, etc.

Checking of busbars on corona. For the previously indicated reasons (§10-1), the busses of the high-voltage installations should not be on a corona, whereupon in open installations the condition that the busses are not on corona in dry and clear weather is usually imposed. Therefore the stranded wires and the tubular busbars, utilized for the set of tires of distributors by a voltage 110 kV are above, the selected on economic current density and checked on let-go current loads, additionally they must be checked to corona. So that the busbar would not display corona, must be observed the condition.

$$U_{уст.ном} < U_{кр} \qquad (10\text{-}3)$$

where $U_{кр}$ - the breaking stress of corona (voltage of the appearance of the visible corona).

If the busbars of three phases are located in the apexes/vertexes of equilateral triangle, then the breaking stress of corona in dry and clear weather, at barometric pressure 76 cm. Hg and temperature of air of 25°C can be determined according to formula [L 5-1 and 7-1]:

$$U_{кр} = 84mr \lg \frac{a}{r}, \qquad (10\text{-}4)$$

where m - the roughness factor, which considers surface condition of busbar and equal to 0.93-0.98 for tubular busbars and single-wire wires, which are long found in air, and 0.83-0.87 for stranded of the wires; r - outside radius of busbar, cm; a - distance between centers of busbars, ~~sm~~ cm.

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If the busbars of three phases are located in one plane, then on average/mean busbar corona begins with voltage, on 4o/o smaller, but on outer busbars - on 6o/o larger $U_{кр}$, determined according to formula (10-4).

From the formula (10-4) it is evident that for increase $U_{кр}$ it is possible to increase the distance between busbars (by phases) a or the diameter of busbars 2 r. Is usually more advantageous an increase in the diameter of busbars, since with an increase in the distance between phases increase sizes/dimensions and cost/value of the supporting structures of distributor.

Checking busbars for thermal resistance by short circuits is conducted in accordance with indications, data in § 7-2. There it is shown, in what cases of busbar it is possible not to check against thermal stability.

During the determination of the heating temperature by the current of short circuiting of multiline busbars it is necessary to consider the current distribution of short circuit in the bands of packet and to determine the temperature of the most loaded with current extreme bands.

Checking busbars for mechanical strength during short circuits. Under the action of the electrodynamic forces, which appear with flows on the busbars of the impact current of short circuiting, the busbars are bent; therefore checking for the mechanical strength of the rigid busbars, attached on stand-off insulators, is reduced to their check calculations to curvature.

Let us examine the mechanical calculation of single-band busbars with the distance between stand-off insulators l (cm) and between the axes of phases a (cm) (Fig. 10-3). The greatest force, which operates on the busbar of average/mean phase, will be determined during three-phase short circuit according to formula (7-3):

$$F^{(3)} = 1{,}76 i_y^{(3)2} \frac{l}{a} 10^{-2} \text{ [kg]}, \qquad (10\text{-}5)$$

where $i_y^{(3)}$ - impact current with three-phase short circuit, kA.

The temperature of busbars changes with a change in their load and temperature of surrounding air. With a change in the temperature of heating busbars is changed their length. Especially considerably busbars are heated and are lengthened with the course on them of short-circuit current. It is obvious that with the rigid fastening of busbars on each stand-off insulator (Fig. 10-3a) this elongation of busbars would lead to their considerable strain (curvature) and onset of the supplementary bending stresses to stand-off insulators. For warning/preventing this, in the first place, fasten the busbars on stand-off insulators not rigidly, but with the possibility of their longitudinal travel with temperature changes their lengths and, in the second place, make on busbars the special flexible compensators of elongation, described below in § 10-3.

Busbars rigidly are fastened to the terminals/grippers of electrical apparatuses and machines, to the outputs of wall entrance insulators and in the places of the branchings of busbars. When, on the busbars, flexible compensators are present, are fastened rigidly the busbars only on stand-off insulators in the middle of the section between two adjacent compensators; on remaining insulators the busbars are fastened freely with the possibility of their longitudinal travel.

Everything said makes it possible to consider busbar during mechanical calculation as the evenly loaded beam/gully with one rigidly attached (pinched) end/lead and free on all other supports. In accordance with this the operating on busbar maximum bending moment can be determined by one of the following formulas [L 10-1]:

with one and two flights/spans

$$M=\frac{F^{(3)}l}{8}\ \overset{(1)}{[\kappa\Gamma c\mathit{м}]};\qquad (10\text{-}6)$$

Key: (1) kg-cm.

with three or larger number of flights/spans

$$M=\frac{F^{(3)}l}{10}\ \overset{(1)}{[\kappa\Gamma c\mathit{м}]}.\qquad (10\text{-}7)$$

Key: (1) kg-cm.

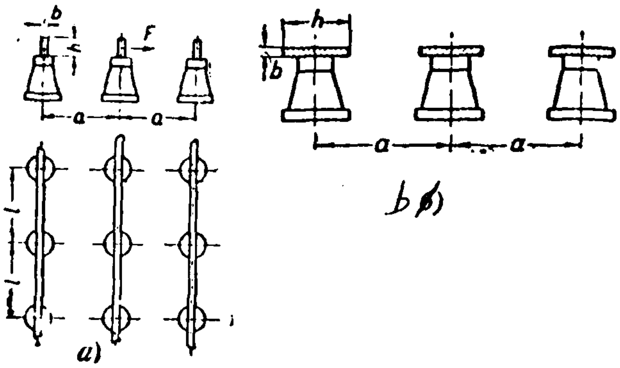

Fig. 10-3. Location of the busbars of rectangular cross section on stand-off insulators. a - location to the edge/fin; b - location prone.

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The voltage of the material of busbar with curvature will be determined according to the formula:

$$\sigma_{расч} = \frac{M}{W} \; [\kappa\Gamma/c\mathit{м}^2]. \qquad (10\text{-}8)$$

Key: (1) kgf/cm².

where W - modulus of section of busbar (in cm³) relative to the axis, perpendicular to line of force.

During the mutual location of rectangular busbars on Fig. 10-3a modulus of section $W=b^2h/6$, and in Fig. 10-3b $W=bh^2/6$.

For the circular busbars of solid section $W=\pi d^3/32\approx 0.1d^3$, while for tubular busbars $W=\frac{\pi}{32}\frac{D^4-d^4}{D}$, where D and d - external and tube bores.

Obtained value $\sigma_{расч}$ must satisfy the condition:

$$\sigma_{расч}\leq\sigma_{доп}. \qquad (10\text{-}9)$$

On PUE [L 3-6] they accept for copper of brand MT. $\sigma_{доп}=1400$ kg/cm²; for aluminum of brand AT $\sigma_{доп}=700$ kgf/cm² and for steel $\sigma_{доп}=$ $=1600$ kgf/cm².

With the nonfulfillment of condition (10-9) it is necessary to attain decrease $\sigma_{расч}$. This it is possible to achieve by reduction in current of short circuit, by change in the mutual location of busbars, by increase in the distance between phases a, decrease of the flight/span between insulators l and finally by an increase in the section of busbars.

If was preliminarily accept the mutual location of rectangular busbars on Fig. 10-3a, then transition/junction for location on Fig. 10-3b gives considerable decrease $\sigma_{расч}$ as a result of the larger moment of resistance of busbars in the second case.

With an increase in the distance between phases a proportionally decreases force $F^{(3)}$, therefore, and which bends moment/torque M and voltage of the material of busbar $\sigma_{расч}$. Increase a is expedient only in such a case, when this does not entail an increase in the overall sizes of distributor or complication and rise in price of the construction/design, during which are fastened the insulators.

A considerably great effect gives the decrease of flight/span l, since on value l depend both the force of $F^{(3)}$, and moment/torque M. Consequently, $\sigma_{расч} \equiv l^2$. Decrease of l is possible in all cases when this is allowed/assumed by the construction/design of distributor. It is logical that the decrease of l entails an increase in the number of stand-off insulators. The in practice used distances between phases and the flights/spans between insulators in different distributors see Vol. 2.

During design frequently there is expedient to determine maximally possible flight/span $l_{макс}$ according to the condition of the mechanical strength of busbars. For this preliminarily select material, sizes/dimensions and section the busbars, are assigned by value $\sigma_{доп}$, take the outline of the mutual location of busbars, value distances a between them they determine their moment of resistance W.

The force of interaction between phases on 1 cm of the length of

busbar can be determined by formula (10-5), after assuming in it $l=1$ cm:

$$f=1{,}76\frac{i_y^{(3)2}}{a}10^{-2}\ [\kappa\Gamma/c\mu]^{(1)}. \qquad (10\text{-}10)$$

Key: (1) kg/cm.

On the basis of formulas (10-7), (10-8) and (10-10) it is possible to compose the following two equations (with a number of flights/spans three and more):

$$M=\frac{F^{(3)}l_{\text{макс}}}{10}=\frac{fl^2_{\text{макс}}}{10} \text{ and } \sigma_{\text{доп}}=\frac{M}{W},$$

joint solution of which gives formula for determining the maximum span between insulators:

$$l_{\text{макс}}=\sqrt{\frac{10\sigma_{\text{доп}}W}{f}}. \qquad (10\text{-}11)$$

Analogously with one or two flights/spans the maximum value of flight/span must not exceed

$$l_{\text{макс}}=\sqrt{\frac{8\sigma_{\text{доп}}W}{f}}. \qquad (10\text{-}11,a)$$

The mechanical calculation of multiline busbars becomes complicated by the fact that each band of packet is bent under the action of two forces: the force of interaction between phases and force of interaction between this band and adjacent bands of the same packet. In this case design voltage of the material of the busbar:

$$\sigma_{\text{расч}}=\sigma_{\phi}+\sigma_{n},$$

where σ_{ϕ} - voltage of the material of busbar from curvature under the action of the force of interaction between the phases; σ_{n} - the same,

under the action of the force of interaction of the bands of one packet.

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The distance between the bands of packet is small; therefore the force of interaction of the bands of one packet and the voltage of material σ_n is usually great. For decrease σ_n between the bands of packet are placed metallic separators (Fig. 10-4), the distance between which is calculated of busbars to mechanical strength. The frequent location of separators is undesirable as a result of deterioration in cooling busbars, high expenditure/consumption of metal and complication of mounting.

The mechanical calculation of busbar/tire construction/design with two-band and busbars is begun from determination σ_Φ. The order of determination σ_Φ the same as in ~~and a~~ the case of single-band busbars. According to formula (10-5) is determined the force of interaction between phases $F_\Phi^{(3)}$, and then by formula (10-6) or (10-7) bending moment M_Φ, applied to packet.

The modulus of section of two-band packet depends on the mutual location of busbars and is determined from one of the following

formulas:

during location on Fig. 10-5a and 10-5b

$$W = 2 \cdot \frac{bh^2}{6} = 0{,}333bh^2; \qquad (10\text{-}12,a)$$

during location on Fig. 10-5c and in the absence of the rigid connection of the bands between themselves

$$W = 2 \cdot \frac{b^2h}{6} = 0{,}333b^2h; \qquad (10\text{-}12,b)$$

during the same location on Fig. 10-5c, but with the rigid connection of the bands of packet, that eliminates their mutual longitudinal displacement and ensuring joint operation them as the elements/cells of composite/compound (spliced) beam/gully[1]

$$W = 1{,}44b^2h. \qquad (10\text{-}12,c)$$

FOOTNOTE [1]. The moment of inertia with respect to axis y-y (Fig. 10-5c) packet of two spliced rectangular busbars by size/dimension bxh each with distance of b between them is equal to:

$$J_y = \frac{(3b)^3h - b^3h}{12} = \frac{26\,b^3h}{12}.$$

ENDFOOTNOTE.

Modulus of section of the spliced beam/gully of the same

relative axis y-y:

$$W_y = \frac{J_y}{05\cdot(3b)} = \frac{26\,b^3h}{12\cdot 1.5b} \approx 1.44\,b^2h.$$

Then is determined the voltage of the material:

$$\sigma_\Phi = \frac{M_\Phi}{W}. \qquad (10\text{-}13)$$

For determination σ_n they first calculate the force of interaction of the bands of packet on 1 cm of their length, using formula (7-1), after assuming in it $l=1$ cm and a=2b (see Fig. 10-2b, and 10-4):

$$f_n = 2.04k_\Phi\,(0.5i_y^{(3)})^2\,\frac{10^{-2}}{2b} = 0.26k_\Phi i_y^{(3)2}\,\frac{10^{-2}}{b}\,[\kappa\Gamma/c\mu]. \qquad (10\text{-}14)$$

(1)

(1) kgf

The distance between the bands of packet is small; therefore here the factor of the form of busbar to consider compulsorily. Are determined it by of the curves of Fig. 7-2.

The maximum bending moment from action forces f_n determine from formula for beams/gullies with the evenly distributed load and the pinched ends/leads:

$$M_n = \frac{f_n\,l_n^2}{12}. \qquad (10\text{-}15)$$

where l_n - a distance between centers of separators, see

The modulus of section in this case is determined from the

formula:

$$W_{\text{и}} = \frac{b^2 h}{6}.$$

Then

$$\sigma_{\text{и}} = \frac{M_{\text{и}}}{W_{\text{и}}}. \qquad (10\text{-}16)$$

It is obvious that must be observed the condition

$$\sigma_{\text{расч}} = \sigma_{\phi} + \sigma_{\text{и}} \leqslant \sigma_{\text{доп}}. \qquad (10\text{-}17)$$

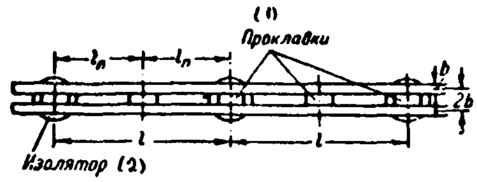

Fig. 10-4. Arrangement/position of the separators between the bands of the packet of busbars.

Key: (1). separators. (2). insulator.

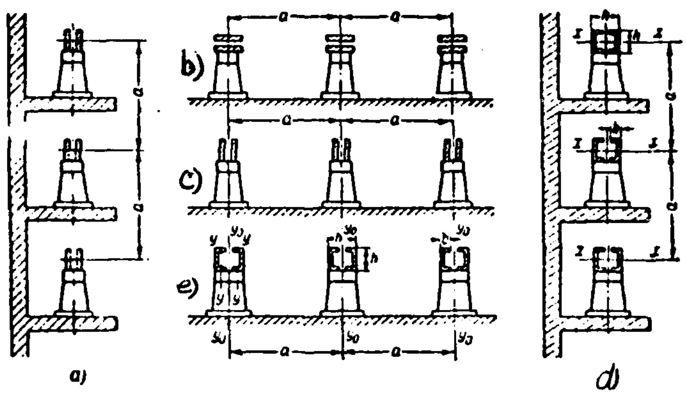

Fig. 10-5. Different cases of location of packets of busbars.

a-c - packets of the flat/plane busbars; d-e - packets of box busbars.

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If condition (10-17) is not satisfied as a result of exaggerated σ_n, then is determined a maximally possible distance between separators $l_{п.макс}$. Are assigned $\sigma_{доп}$ and, knowing $\sigma_{ф}$, they determine $\sigma_{п\,доп} = \sigma_{доп} - \sigma_{ф}$.

Being guided by formulas (10-15) and (10-16), it is possible to write:

$$\frac{f_п l^2_{п.макс}}{12} = \sigma_{п\,доп} W_п,$$

whence

$$l_{п.макс} = \sqrt{\frac{12\sigma_{п\,доп} W_п}{f_п}}. \qquad (10\text{-}18)$$

The calculation of three-band busbars is given in [6-1 and 7-2].

The mechanical calculation of busbar/tire construction/design from box busbars also consists in determination $\sigma_{расч} = \sigma_ф + \sigma_п$. For determination $\sigma_ф$ they use formulas (10-5), (10-6) or (10-7) and (10-13). The entering the latter/last formula modulus of section of packet of two box busbars they take as the equal to:

during location on Fig. 10-5d

$$W = 2W_x; \qquad (10\text{-}19,a)$$

during location on Fig. 10-5e and in the absence of the rigid connection of the box busbars of packetbetween themselves

$$W = 2W_y; \qquad (10\text{-}19b)$$

during the same location on Fig. 10-5e, but with the rigid connection of the box busbars of packet, which ensures their combined work as the elements/cells of spliced beam,

$$W = W_{y0}. \qquad (10\text{-}19e)$$

where W_x and W_y - moduli of section of box busbars of relatively principal axes of inertia with respect x-x and y-y.

W_{y0} - moment of resistance of packet of two rigidly connected box busbars relative to the inertia axis of packet y_0-y_0.

The values of values W_x, W_y and W_{y0} are given in table P-10.4.

For determining the voltage of material from interaction of the busbars of one phase σ_n it is necessary to, first of all, determine the force of interaction between them f_n. A precise computation of value f_n with the box busbars of sufficient is complicated and it is labor-consuming [10-2]. At the same time in practical calculations with sufficient accuracy it is possible to determine f_n by formula (10-14), after placing in it $k_\phi = 1$ and having simultaneously accepted for the calculated distance between box busbars 2b=h, i.e., The distance between the external faces of box busbars (Fig. 10-5e)

[10-3]. Under these conditions:

$$f_n = 2{,}04\,(0{,}5 i_y^{(3)})^2 \frac{10^{-2}}{h} = 0{,}51\, i_y^{(3)2} \frac{10^{-2}}{h}\ [\kappa\Gamma/c\text{м}]^{(1)}.\ (10\text{-}20)$$

Key: (1). kgf/cm.

Further they determine M_n by formula (10-15), and then σ_n according to formula (10-16), after accepting in it the modulus of section of box busbar relative to axis y-y (Fig. 10-5e), i.e., $W = W_y$ (see table P-10.4).

As a result of calculations must be carried out condition (10-17).

If necessary the maximum permissible distance between the separators of the busbars of one phase can be determined by formula (10-18), substituting in it $W_n = W_y$.

The mechanical calculation of busbars during the location of phases according to the apexes/vertexes of triangle is presented in [10-2].

The bare stranded wires, fastened on suspension insulators in installations 35 kV it is above, are checked against mechanical strength just as wires of electric power lines taking into account

the dead weight of wires, weight of ice-covered surface, wind pressure [7-1].

Example of 10-1. To select busbars in the circuit of the waste/exiting cable line by the voltage 10 kV, that feeds substation on diagram in Fig. 8-3b. Load of the sections of substation $S_1=S_2=2.9$ MVA. Sectionalizing switch SV it is normally disconnected. With emergency disconnection of one of the lines the switch SV is included automatically and both sections the pin of substation are supplied by one line. Demand time of a peak load of substation $T_{макс}=4000$ h.

Short-circuit currents during closing/shorting in the beginning of the cable of the waste/exiting line:

$$I''^{(3)}=27 \overset{(1)}{ка}; \quad I_{\infty}^{(3)}=13 \overset{(1)}{ка}; \quad I_{\infty}^{(2)}=16{,}5 \overset{(1)}{ка}.$$

Key: (1). kA.

Time of triggering of relaying of waste/exiting line $t_{защ}=1{,}35$ s, tripping time of switch $t_в=0{,}15$ s.

In the construction/design of the distributor of busbar accepted are arranged/located on the outline of Fig. 10-3b with $l=0{,}8$ m and a=25 cm, in this case in the individual sections of the busbars between apparatuses a number of flights/spans one or two.

Busbars are aluminum. Temperature of air of 25°C.

Selection of the section of busbar on economic current density. the current of the normal load of line (busbar):

$$I_{н} = \frac{S_1}{\sqrt{3}U} = \frac{2\,900}{\sqrt{3}\cdot 10} = 167 \text{ A.}$$

On Table 10-1 with $T_{макс} = 4000$ h we find $j_{эк} = 1{,}1$ A/mm², then

$$s = \frac{I_{н}}{j_{эк}} = \frac{167}{1{,}1} = 152 \text{ мм}^2.$$

On table P-10.1 we accept the aluminum busbar of the nearest section 40•4=160 mm² with the long let-go current of load $I_{доп} = 480$ A.

checking busbar to the maximum prolonged current of load. With emergency cutoff/disconnection of one of the lines (Fig. 8-3b) the second is loaded by doubly high current $I_{н.макс} = 2\cdot 167 = 334$ A.

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Since $I_{доп} > I_{н.макс}$, then the temperature of busbar will be less $\theta_{н} < 70°$ C.

Checking busbar to thermal stability during short circuit.

[illegible] of the selected busbar with peak load we

determine from formula (7-16):

$$\vartheta_{н} = \vartheta_{0} + (\vartheta_{доп} - \vartheta_{0}) \frac{I^2_{н.макс}}{I^2_{доп}} = 25 + (70-25)\frac{334^2}{480^2} \approx 50^\circ \text{ C.}$$

The estimated time of the action of short-circuit current:

$$t = t_{защ} + t_{в} = 1{,}35 + 0{,}15 = 1{,}5 \overset{(1)}{сек.}$$

Key: (1). s.

Aperiodic component/term short-circuit current is not considered, since t>1 s.

during the three-phase short circuit:

$$\beta''^{(3)} = \frac{I''^{(3)}}{I^{(3)}_{\infty}} = \frac{27}{13} \approx 2{,}1.$$

Through of the curves of Fig. 7-6 we find $t^{(3)}_{ф} = 2{,}1$ s, then

$$I^{(3)2}_{\infty} t^{(3)}_{ф} = 13^2 \cdot 2{,}1 \approx 355 \overset{(1)}{ка^2 \cdot сек.}$$

Key: (1). $kA^2 \cdot s$.

During the two-phase short circuit:

$$\beta''^{(2)} = \frac{I''^{(2)}}{I^{(2)}_{\infty}} = \frac{0{,}87 \cdot 27}{16{,}5} \approx 1{,}4.$$

Through of the curves of Fig. 7-6 we find $t^{(2)}_{ф} \approx 1{,}5$ s, then the current

$$I^{(2)2}_{\infty} t^{(2)}_{ф} = 16{,}5^2 \cdot 1{,}5 \approx 410 \overset{(1)}{ка^2 \cdot сек.}$$

Key: (1). kA²•s.

Consequently, to the thermal resistance of busbar it is necessary to check during two-phase short circuit.

When $\vartheta_н = 50°C$ on curve for aluminum on Fig. 7-7 we find:

$$A_н \approx 0{,}4 \cdot 10^4,$$

then

$$A_к = A_н + \left(\frac{I_\infty}{s}\right)^2 t_ф = 0{,}4 \cdot 10^4 + \left(\frac{16\,500}{160}\right)^2 \cdot 1{,}5 \approx 2{,}0 \cdot 10^4.$$

Through the curve of Fig. 7-7 we find $\vartheta_к \approx 325°C$. Since for aluminum busbars $\vartheta_{к.макс} = 200°C$, then the selected busbar is thermally unstable.

Let us determine the minimum section of the busbar, stable during shorting.

When $\vartheta_{к.макс} = 200°C$ through the curve of Fig. 7-7 we find $A_{к.макс} = 1{,}35 \cdot 10^4$, then $A_{к.макс} - A_н = (1{,}35 - 0{,}4) \cdot 10^4 =$ 0.95•10⁴, also, according to formula (7-14):

$$s_{мин} = I_\infty \sqrt{\frac{t_ф}{A_{к.макс} - A_н}} = 16\,500 \sqrt{\frac{1{,}5}{0{,}95 \cdot 10^4}} \approx 210\ мм^2,$$

and according to simplified formula (7-15):

$$s_{мин} = \frac{I_{\infty}}{C}\sqrt{t_{ф}} = \frac{16\,500}{90}\sqrt{1,5} \approx 220\ мм^2.$$

Taking into account that during the replacement of busbar 40•4 mm² to the busbar of larger section its temperature to short circuit will be below normal, should be to avoid overexpenditure of aluminum checked the possibility of the selection of the busbar of smaller section, i.e., 40•5=200 mm² when $I_{доп} = 540\ A$ (Table P-10.1). Check this busbar for heating by short-circuit current:

$$\vartheta_{н} = 25 + 45\cdot\frac{334^2}{540^2} \approx 40°\ C;\ A_{н} \approx 0,3\cdot 10^4;$$

$$A_{к} = 0,3\cdot 10^4 + \left(\frac{16\,500}{200}\right)^2\cdot 1,5 \approx 1,3\cdot 10^4\ и\ \vartheta_{к} \approx 180°\ C,$$

which for aluminum busbars is admissible.

Checking busbar to mechanical strength.

Impact short-circuit current:

$$i_{y} = 1,8\sqrt{2}I'' = 2,55\cdot 27 \approx 69\ \overset{(1)}{ка}.$$

Key: (1). kA.

Effort for average/mean phase according to formula (10-5):

$$F = 1,76 i_{y}^{2}\frac{l}{a}10^{-2} = 1,76\cdot 69^2\cdot\frac{80}{25}\cdot 10^{-2} = 268\ \overset{(1)}{кГ}.$$

Key: (1). kgf.

The moment/torque, which bends busbar, we determine from formula (10-6):

$$M = \frac{Fl}{8} = \frac{268 \cdot 80}{8} = 2\,680 \ \overset{(1)}{\kappa\Gamma c\mathit{m}}.$$

Key: (1). kgf cm.

Modulus of section of the busbar:

$$W = \frac{bh^2}{6} = \frac{0{,}5 \cdot 4^2}{6} \approx 1{,}33 \ c\mathit{m}.^3$$

Voltage of the material of the busbar:

$$\sigma_{\text{расч}} = \frac{M}{W} = \frac{2\,680}{1{,}33} \approx 2\,000 \ \overset{(1)}{\kappa\Gamma/c\mathit{m}^2},$$

Key: (1). kgf/cm².

what considerably exceeds $\sigma_{\text{доп}} = 700$ kgf/cm² for aluminum busbars.

If according to structural/design conditions in the distributor accepted it is not possible to change value l and a, then it is necessary to select the busbar of larger section.

According to formula (10-8):

$$W = \frac{M}{\sigma_{\text{доп}}} = \frac{2\,680}{700} = 3{,}83 \ c\mathit{m}^3.$$

Thus, must be selected the busbar for which $W = bh^2/6 \geq 3.83$ cm³. Being guided these Table P 10.1, we find that by the nearest busbar,

which satisfies this condition, is the aluminum busbar section 80•6 mm² when $I_{доп}=1150$ a.

The insulators of busbar/tire construction/design we select, being guided by indications §9-5 and data of Table P-9.

We select stand-off insulators for internal installation to voltage 10 kV of the type OB-10 which allow/assume load $F_{доп}=0,6\cdot750=450$ kgf, which is less than the calculated effort/force to insulator F=268 of kgf.

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Altitude correction of busbar we do not make, since busbar lies/rests prone on insulator.

Wall entrance insulator is selected type Pa-10 on 400A, since $F_{доп}=225$ kgf $> F_{расч}=\frac{F}{2}=134$ kgf.

If the construction/design of distributor allows, then it is possible to decrease the distance between insulators, i.e., the flight/span between the attachment points of busbars. Being guided by formulas (10-11) and (10-11a), let us find that with selected according to the conditions of normal mode aluminum busbar 40x4 mm

and with a=25 cm the great distance between insulators along the length of busbar must not exceed:

for the sections of busbars with one and two flights/spans

$$l_{\text{макс}} = \sqrt{\frac{8 \cdot 700 \cdot 1{,}33}{3{,}35}} \approx 47 \text{ см},$$

but for the sections of busbars with three and by a large number of flights/spans

$$l_{\text{макс}} = \sqrt{\frac{10 \cdot 700 \cdot 1{,}33}{3{,}35}} \approx 53 \text{ см};$$

where

$$f = \frac{F}{l} = \frac{268}{80} \approx 3{,}35 \text{ кГ/см.}^{(1)}$$

Key: (1). kgf/cm.

In the necessary cases change both the sizes/dimensions of busbar/tire construction/design l and a and section the busbars, attaining the creation of most economical construction/design.

Example of 10-2. To select busbars and insulators of busbar in the circuit of the generator with a power of 37.5 MVA. Busbar partially is passed to the condensation location of machine room and partially in the open air between the machine room and the distributor of generator voltage. Nominal voltage of installation 10 kV. Short-circuit currents during closing/shorting in the circuit of the generator:

$$i_y^{(3)} = 85 \overset{(1)}{\text{ка}};\ I''^{(3)} = 32 \overset{(1)}{\text{ка}};\ I_\infty^{(3)} = 23 \overset{(1)}{\text{ка}}\ (I_\infty^{(3)} > I_\infty^{(2)}).$$

Key: (1). kA.

Demand time of a peak load for generator $T_{\text{макс}} = 6500$ h.

Triggering time of relaying of generator $t_{\text{защ}} = 0{,}1$ s, tripping time of switch in the circuit of generator $t_{\text{в}} = 0{,}2$ s.

Location of busbars to accept on outline in Fig. 10-5b, with $l = 1{,}5$ m and a=0.7 m.

Busbars are aluminum. Temperature of air of 25°C.

Selection of the section of busbar on economic current density. The rated current of the generator

$$I_{\text{г.ном}} = \frac{37{,}5}{\sqrt{3} \cdot 10{,}5} = 2{,}06 \text{ A}.$$

On Table 10.1 with $T_{\text{макс}} = 6500$ h we accept $j_{\text{эк}} = 1$ A/mm², then s=2060/1=2060 mm².

On table P-10.1 we accept two-band busbar 2•(100•10)=2000 mm², when $I_{\text{доп}} = 2860$ A.

Checking busbars to the maximum prolonged current of load. The

greatest prolonged current of the load of generator $I_{н.макс}=\frac{37,5}{\sqrt{3}\cdot 10}=2,16$ kA the less long let-go current of the load of the selected packet of busbars; therefore the temperature of busbars will be less $\vartheta_{доп}=70°$ C.

Checking busbars to thermal stability. Temperature of busbar to short circuit $\vartheta_н=25+45\cdot\frac{2\,160^2}{2\,860^2}\approx 50°$ C.

The estimated time of the action of short-circuit current: t=0.1+0.2=0.3 s.

We determine the fictitious time of action of short-circuit current taking into account aperiodic component/term, since t<1 s:

$$\beta''=\frac{32}{23}\approx 1,4;\quad t_{ф.п}=0,4 \text{ сек. }(1)$$
$$t_{ф.а}=0,05\beta''^2=0,05\cdot 1,4^2\approx 0,1 \text{ сек. }(1);$$
$$t_ф=t_{ф.п}+t_{ф.а}=0,5 \text{ сек. }(1)$$

Key: (1). s.

We further use curve for aluminum in Fig. 7-7: $A_н=0,38\cdot 10^4$;

$$A_к=0,38\cdot 10^4+\left(\frac{23\,000}{2\,000}\right)^2\cdot 0,5\approx 0,39\cdot 10^4,$$

with which $\vartheta_к\approx\vartheta_н$.

Using the case, let us note that the calculated for large operating currents current-carrying parts of the main chains of

electrical stations and substations (generators, powerful/thick step-up and step-down transformers, collecting mains, etc.) are usually they are thermostable during short circuits, especially during use in these circuits of high speed relayings.

Checking busbars to mechanical strength. Force of interaction between the phases:

$$F=1{,}76\cdot 85^2\cdot \frac{150}{70}\cdot 10^{-2}=274\ \overset{(1)}{\text{кГ}}.$$

Key: (1). kgf.

Bending moment according to formula (10-7):

$$M=\frac{Fl}{10}=\frac{274\cdot 150}{10}=4\,100\ \overset{(1)}{\text{кГсм}}.$$

Key: (1). kg/cm.

Moment of resistance according to formula (10-12a):

$$W=0{,}333bh^2=0{,}333\cdot 10^2=33{,}3\ \text{см}^3.$$

Key: (1). cm³.

Voltage of material from interaction between the phases:

$$\sigma_\phi=\frac{4\,100}{33{,}3}=123\ \overset{(1)}{\text{кГ/см}^2}.$$

Key: (1). kgf/cm².

Let us determine a number of separators between the bands of packet and a distance between them. Let us accept for aluminum busbars $\sigma_{доп}=700$ kgf/cm², then $\sigma_{п.доп}=\sigma_{доп}-\sigma_{ф}=700-123=577$ kgf/cm².

The factor of the form of busbar is determined on of the curves of Fig. 7-2:

$$m=\frac{b}{h}=\frac{10}{100}=0{,}1;\ \frac{a-b}{b+h}=\frac{2b-b}{b+h}=\frac{10}{110}=0{,}09;$$

$$k_{ф}=0{,}42.$$

Force of interaction between the bands of packet on 1 cm of the length of busbar according to formula (10-14):

$$f_{п}=0{,}26k_{ф}i_{y}^{2}\frac{10^{-2}}{b}=0{,}26\cdot 0{,}42\cdot 85^{2}\cdot 10^{-2}=7{,}9\ \overset{(1)}{кГ/см}.$$

Key: (1). kgf/cm.

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A maximally possible distance between separators we determine from formula (10-18):

$$l_{п.макс}=\sqrt{\frac{12\cdot 577\cdot 10}{7{,}9\cdot 6}}\approx 38\ см.$$

Since the flight/span between insulators is accepted l by 150 cm, then the separators between the rhodes of packet must be

established/installed through every 37.5 cm, counting between their axes: in the places of the attachment of packet on insulators and three additional separators in the flight/span between insulators.

Selection of insulators. For a busbar of the type OB-10 on nominal voltage 10 kV, permissible load $F_{доп}=450$ the kgf (see table P-9), that the less specific above force of interaction between phases F=274 of kgf.

For the external part of the busbar we select bolt supporting/reference insulators of the type ShN-10 to voltage 10 kV and $F_{доп}=300$ kgf.

For the output of busbar from machine room and distributor we select linear conclusions of the type PNV-20/3000 to voltage 20 kV, nominal current 3000 A and $F_{доп}$ 750 the kgf (to voltage 10 kV linear conclusion/output are manufactured to rated currents to 2000 A inclusively, and in our case $I_{н.макс}$ of 2160 A).

Example of 10-3. Select collecting mains by the voltage 10 kV of powerful/thick power plant. The maximum current of the load of collecting mains composes $I_{н.макс}=4{,}5$ kA. Impact short-circuit current $i_y=170$ kA. The phases of collecting mains are located in horizontal plane with $l=120$ cm and a=75 cm.

Busbars are aluminum. Temperature of air of 25°C.

The section of collecting mains by economical current density they do not select; therefore we select the section of busbars on the maximum current of load.

On Table P 10.1 it is possible to select packet of four aluminum busbars by the size/dimension 120x10 of mm, by total cross-sectional area to phase 4•1200=4800 mm² with $I_{доп}=4650$ A.

On Table P-10.4 it is possible to select two box busbars to phase with the sizes/dimensions of sides 125 mm and 55 mm, thickness of 6.5 mm, by total cross-sectional area to phase 2•1370=2740 mm² with $I_{доп}=4640$ A.

Is completely obvious the advisability of the selection of box busbars.

The busbars of large cross sections, as noted above, are usually thermostable; therefore we will be restricted to checking busbars to mechanical strength. The location of box busbars let us accept on the outline of Fig. 10-5e.

According to formula (10-5):

$$F = 1{,}76 \cdot 170^2 \cdot \frac{120}{75} \cdot 10^{-2} \approx 810 \overset{(1)}{\text{кГ}}.$$

Key: (1). kgf.

According to formula (10-7):

$$M = \frac{810 \cdot 120}{10} = 9\,750 \overset{(1)}{\text{кГсм}}.$$

Key: (1). kg-cm.

Let us assume that the box busbars between themselves are not rigidly connected, then the modulus of section of packet is determined according to formula (10-19b):

$$W = 2W_y = 2 \cdot 9{,}5 = 19 \text{ см}^3,$$

where $W_y = 9{,}5$ cm³ is undertaken on table P-10.4 for the selected busbar with h=125 mm.

According to formula (10-8):

$$\sigma_\phi = \frac{9\,750}{19} \approx 510 \overset{(1)}{\text{кГ/см}^2}.$$

Key: (1). kgf/cm².

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According to formula (10-20):

$$l_n = 0{,}51 \cdot \frac{170^2}{12{,}5} \cdot 10^{-3} = 11{,}8 \text{ кГ/см.}^{(1)}$$

Key: (1). kgf/cm.

When $\sigma_{п.доп} = 700-510=190$ kgf/cm² and $W_n = W_y = 9{,}5$ cm³ the great possible distance between centers of separators according to formula (10-18) will comprise:

$$l_{п.макс} = \sqrt{\frac{12 \cdot 190 \cdot 9{,}5}{11{,}8}} = 43 \text{ см.}$$

Since $l = 120$ cm, the distance between centers of separators we accept $l_n = 40$ cm.

In the case of the rigid connection of busbars in packet during determination σ_Φ one should accept according to formula (10-19c) $W = W_{y_0} = 100$ cm³ (see table P-10.4), then:

$$\sigma_\Phi = \frac{9\,750}{100} \approx 97 \text{ кГ/см}^2;^{(1)}$$

$$\sigma_{п.доп} = 700 - 97 = 603 \text{ кГ/см}^2;^{(1)}$$

$$l_{п.макс} = \sqrt{\frac{12 \cdot 603 \cdot 9{,}5}{11{,}8}} \approx 76 \text{ см.}$$

Key: (1). kgf/cm².

i.e. in the flight/span between the insulators of sufficient busbar

to connect by one plank as this is shown in Fig. 10-6. Plancks fulfill from the same material, as busbar. Plancks weld on to box busbars, moreover in the flight/span between insulators must be not less than three planks (Fig. 10-6). Extreme planks should be welded on as near as possible to stand-off insulators.

From that presented it is clear that the connection of busbars with planks leads to decrease both $\sigma_{ф}$ and $\sigma_{п}$.

The calculation of planks is given in [10-2].

For the calculated above collecting mains should be used the stand-off insulators of the type of the OD-10 when $F_{доп}$ = 1200 kgf.

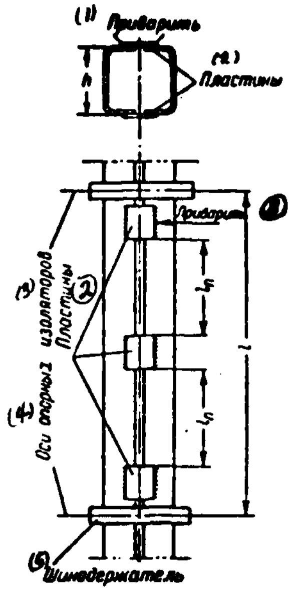

Fig. 10-6. Arrangement/position of the planks, welded on to box busbars.

Key: (1). To weld on. (2). Plates. (3). insulators. (4). Axes are supporting/reference I. (5). busbar holder.

10.3. Attachment of busbars on insulators. Coloration of busbars.

Attachment of busbars on stand-off insulators. The busbars of rectangular and box section are secured on stand-off insulators with the aid of busbar holders (Fig. 10-7). In the installations of

alternating current the steel parts of busbar holder are heated by eddy currents, also, as a result of hysteresis. For decreasing this heating, which is especially important with the large operating currents (1-1.5 kA and more), is fulfilled the upper plank of busbar holder from nonmagnetic material - from non-magnetic cast iron or from copper with copper busbars and from aluminum with aluminum busbars. For the same targets sometimes they insulate by separators from insulating cardboard of the part of busbar holder.

Circular busbars are fastened on stand-off insulators with the aid of clamps.

Patch cords attach to string insulator with the aid of special terminals/grippers.

On those stand-off insulators on which must be provided the free longitudinal travel of busbar with a change in its temperature of heating (see above), between the busbar and upper plank of busbar holder 5 must be small gap, approximately/exemplarily 1.5-2 mm. Is reached this with the aid of spacing tubes with 4, put on to pins 6 or bolts of 8 busbar holders.

In the rectangular sections of busbars long than 20 m with aluminum and more than 30-35 m with copper became are

established/installed the compensators of the elongation of busbars (Fig. 10-8), which are of the series/row of the strips in thickness 0.2-05 mm of the same material, as busbar, in the quantity, which corresponds to the section of busbar. With busbars in thickness to 8 mm are applied also the compensators, prepared via the U-shaped curvature of busbar itself.

In the small sections of busbars (between apparatuses, between the apparatus and wall entrance insulator, etc.) for the compensation for elongation the busbars fulfill special curvatures of tire (Fig. 10-9a, b) or establish flexible members (Fig. 10-9c), and with the large cross section of busbars - compensators. These devices/equipment decrease the effort/force, transmitted to terminal/gripper and insulator of apparatus during the temperature elongations of busbar.

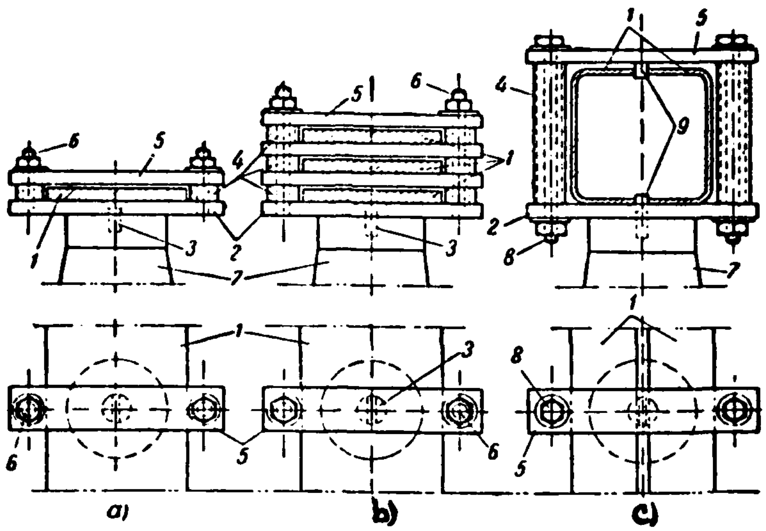

Fig. 10-7. Attachment of aluminum busbars on stand-off insulators. a) the single-band busbar; b) packet of three bands; c) packet of two busbars of box section. 1 - busbar; 2 - steel plank; 3 - screw/propeller; 4 - distance steel tube; 5 - aluminum plank; 6 - pin, screwed into plank 2; 7 - insulator; 8 - bolt; 9 - spacer.

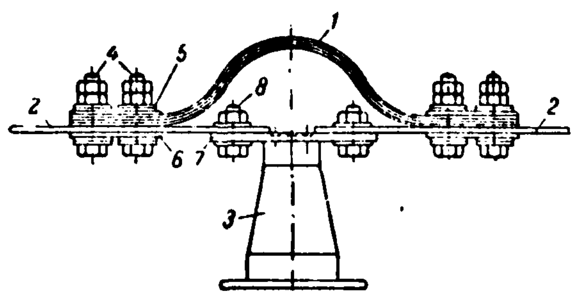

Fig. 10-8. Busbar/tire compensator of semicircular form. 1 - compensator; 2 - busbar; 3 - the stand-off insulator; 4 - bolts for

the attachment of the compensator; 5 - washer; 6 - backing/block; 7 - cover plate, fixed by screws/propellers to the cap/hood of the insulator; 8 - bolts for the attachment of busbars (in the cover plate of 7 bolt holes 8 circular, according to the diameter of bolts, but in the busbars of 2 openings/apertures oval for the free displacement/movement of the busbars; bolts 8 they are not involved/tightened).

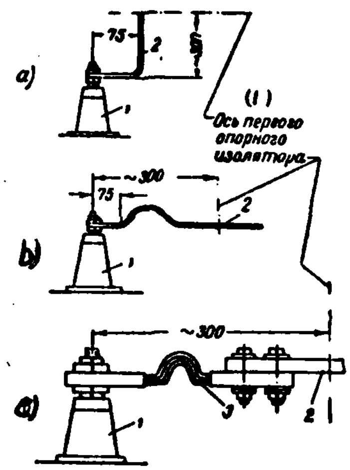

Fig. 10-9 examples of the connection of rigid busbars to the introductions/inputs of apparatuses. a and b) curvature of tire before the introduction/input; c) the installation before the introduction/input of the separate compensator; 1 - insulator of the apparatus; 2 - (introduction/input) the busbar; 3 - compensator.

Key: (1) Axis of the first support insulator.

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Coloration of busbars. The coloration of busbars, as noted earlier, somewhat increases heat emission into the environment, which increases the let-go current of load on busbars. The coloration of steel busbars prevents/warns their corrosion. Taking into account this, entire rigid busbars they tincture with enamel paints. At the same time for facilitation the orientations of personnel apply the colored coloration of busbars with the paints/colors of following colors [10-4].

Direct current:

the busbar of positive pole - red;

the busbar of negative pole - blue.

Three-phase current:

the busbar of phase A - yellow;

the busbar of phase B - green;

the busbar of phase C - red.

Zero busbars:

with the ungrounded neutral - white;

with grounded neutral - violet.

It is opened the laid grounding conductors, and also all constructions/designs, wires and bands of the network of grounding - violet.

Stranded patch cords they do not tincture, since a change in their sagging with a change in the heating temperature leads to the decomposition of paint coat. For facilitating the discrimination of phases should be applied the colored coloration of the armature of string insulators.

The walls of locations tincture in tints, and the metal constructions into gray ones, blacks, etc. of color against the background of which the distinctive coloration of busbars distinctly is separated/liberated how is provided the greater safety of servicing distributing devices/equipment.

Chapter eleven.

POWER CABLES.

11.1. Types of cables and their use/application.

On electrical stations and substations power cables apply for the connection of generators and transformers with distributors, for supply the feeds to the electric motors of their own needs, etc. The outputs of lines by the voltage 6-10 kV of electrical stations and powerful/thick substations frequently fulfill by cables, also, when external network is carried out air. In certain cases find a use the cables by voltage 35 kV and above.

In the three-wire installations of three-phase current are applied triple-cores cable with the copper and aluminum veins/strands, comprised of a large number of wires of a small section (for imparting to cable the flexibility).

In the form of an example Fig. 11-1 shows the device/equipment of that of very propagated on electrical stations and substations of triple-core cable of brand SBG with copper veins/strands with the paper saturated insulation in lead covering (S), armored (B), without

external deposit above armor (G - bare).

To veins/strands 1 is attached sectional mold for decreasing outer diameter of cable how is achieved the decrease of the expenditure of insulation and metal for its external shielding deposits.

With round veins/strands are prepared the cables from 1 to 6 kV by section to 16 mm² and cables by voltage 20 and 35 kV.

Each cable core is isolated/insulated by cable paper 2, saturated with insulating compound. Around isolated/insulated and together those twisted cores superimposed zonal insulation 4, also from the saturated cable paper, which is the supplementary isolation of veins/strands from grounded lead covering 5. Intervals between veins/strands and zonal insulation are filled with yarn 3.

Above zonal insulation the cable is pressed by lead covering 5, which shields isolation from moisture and not allowing/assuming the efflux of impregnating composition.

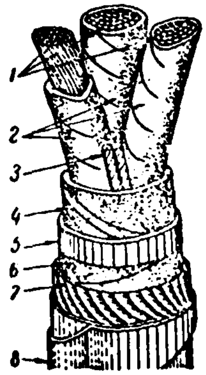

Fig. 11.1. Triple-core cable with sector veins/strands of the type SBG. 1 - current-carrying veins/strands; 2 - the cable paper (insulation of core); 3 - Jute filler; 4 - zonal insulation (the cable paper); 5 - the lead covering; 6 - the paper tape; 7 - Jute shielding deposit; 8 - steel armor (two tapes).

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The latter would lead to drying of paper insulation, to decrease in its dielectric strength and danger of its breakdown.

For protection from mechanical cable faults is equipped with steel armor 8, made from two steel zinc-coated tapes. Between armor and lead covering there is a shielding deposit from saturated paper tape 6, superimposed to lead covering on the layer of bituminous

composition, and the layer of yarn 7. This deposit shields lead covering from mechanical damages by steel armor and from the chemical effect of the environment. This cable is suitable for a separator in the open air - in channels, tunnels, etc. After separator the cable armature must be painted by black asphalt varnish for corrosion protection.

Steel armor of the run in the earth/ground cable must be shielded from corrosion by shielding deposit. As an example it is possible to indicate the cables of brand SB, which differ from the cables of brand SBG in terms of the fact that they above steel armor have the external deposit, which consists of bituminous composition, saturated yarn and lime coating.

Separator within buildings and in the channels of cables with external deposit from saturated yarn is not admitted according to the condition of fire safety, since yarn easily will be ignited also on it can be propagated the fire/light.

The cables of the same construction/design, but with aluminum veins/strands have the designation of brands ASBG and ASB.

All cables indicated above are manufactured to voltages to 10 kV inclusively. They are suitable for a separator in the earth/ground

and in air.

Analogous cables with aluminum shell (instead of the lead) are applied with separator in air and in the earth/ground (with the copper veins/strands of brands ABG and AB, and with the aluminum veins/strands of brands AABG and AAB).

If not the danger of mechanical damages, then it is possible to apply cheaper cables without steel armor (brands SG and ASG - with copper and aluminum veins/strands, but to lead covering, without external deposit, i.e., bare; brands SA and ASA - the same cables, but with supplementary deposit on lead shell of bitumen and saturated yarn; brands AG, AAG, AA and AAA - analogous cables, but with shielding aluminum shell instead of the lead).

For installations by voltage to 1000 V are manufactured also the paper-insulated cables in polychlorovinyl shell, suitable for a separator in the earth/ground and in air (with the copper veins/strands of brands VMBG and VMB; with the aluminum veins/strands of brands AVMBG and AVMB).

Paper-insulated cables cannot be run vertically with large difference of levels (more than 15-25 m) due to efflux from the cable of impregnating compound and desiccation of the upper part of the

cable. To nominal voltages 6 and 10 kV by Moscow cable works are manufactured triple-cores cable with the copper and aluminum veins/strands with section 25-240 mm² isolated/insulated by the saturated not discharging mass by the cable paper in lead covering, which can be run on vertical and sharply inclined routes without the limitation of a difference in the levels of the separator (cables of brands TsSB, TsASB, TsSBG, TsASBG, TsSBN, TsASBN, etc., where the letter Ts it indicates the ceresin-80, introduced into impregnating compound, and letter N - incombustible shielding deposit). Permissible loads on these cables the same and on power cables with the saturated paper insulation of the same sections and voltages and analogous constructions/designs.

On vertical and sharply inclined routes with a difference in the levels to 50-100 m are applied also the cables with an impoverished-saturated insulation of brands SBGV and SBV.

With voltages to 6 kV inclusively without the limitation of differences in the levels of separator it is possible to apply india-rubber cables (into the designation of cable make-up additionally enters letter R, for example, SRBG, SRB, etc.). These cables are more expensive than paper-insulated cables; their permissible load is less as a result of the smaller permissible temperature of heating rubber insulation. For example, for cables to

voltage 1000 V with paper insulation the long permissible temperature of vein/strand $\theta_{доп}=80°C$, and for india-rubber cables $\theta_{доп}=55°C$. Furthermore, india-rubber cables to undesirably apply in installations with the temperature of air of 35°C even more.

Cables to voltages 20 and 35 kV manufacture with the separately lead-lined veins/strands (brands OSBG and OSB or AOSBG and AOSB). The same cables, but with an impoverished-saturated insulation, manufacture to voltages 6 and 10 kV (brands OSBGV and OSBV).

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In installations by voltage 110 kV and above are applied oil-filled and gas-filled cables [5-1]. The latter manufacture also to voltages 10 and 35 kV.

In the four-wire installations of three-phase current with neutral conductor by voltage 380/220 and 220/127 V apply four-wire cables.

In the installations of alternating current it is not possible to apply the single-cable armored cables, since in this case the total magnetic flux of cable is not equal to zero (as with triple-core cable) and is closed in steel armor. The latter is

strongly heated by eddy currents, also, as a result of hysteresis, which leads to overheating and decomposition of the insulation of cable.

On direct current are applied as one- and two-core cables with steel armor.

On electrical stations and substations the cables usually run in channels and tunnels. Separator in trenches (in the earth/ground) impedes observation of cables and their maintenance/servicing.

For warning/preventing of damage to insulation and shielding deposits of cables it is necessary that with the separator all their curvatures would be fulfilled with the bending radii: R≥25D for single-cable ones and R≥15D for multicore cables in lead ones and in the aluminum shells, armored and not armored where D - an outside diameter of cable (with armor). For india-rubber cables in the lead and polychlorovinyl shells of those armored R≥10D and of those not armored R≥6D.

For the purpose of the prevention of efflux from the cables of impregnating compound and penetration in them of moisture, which unavoidably leads to the breakdown of the insulation of cables, the ends/faces of cables reliably seal with the aid of the various kinds

of the end fittings: terminals or steel funnels, poured with cable filling compound, dry preparings.

Recently on cables by voltage to 10 kV all more widely inclusively fulfill the end fittings of the epoxy trowelling compound. The latter consists of epoxy resin (45o/o), which is synthetic material, talc (34o/o) and small quantity of other substances and is dense doughy red-brown mass. During the mounting of preparings into this compound is introduced a small quantity of hardener under action of which the compound hardens with the formation of the monolithic mass, which possesses high ones and constants in operation by the electrical properties. Fig. 11-2 shows the general view of the end fitting of cable from the epoxy trowelling compound, and in table P 11.7 are given its basic dimensions.

After preparing core of cable as this shown in Fig. 11-2, to cable they put on detachable metal mold and pour by the epoxy trowelling compound, having preliminarily introduced into it hardener. After the solidification of the compound (several days) form remove/take. Finished seal from epoxy compound does not have shielding housing and insulators as a result of high mechanical and dielectric strength of the hardened compound.

Seals from the epoxy trowelling compound are reliable, cheap, they can be applied in heated and unheated dry and damp/crude premises with relative atmospheric humidity to 95o/o [11-1]. Their to establish is possible verticaliy, it is horizontal and it is inclined at any angle.

The individual sections of caoles connect with the aidof couplings [7-1].

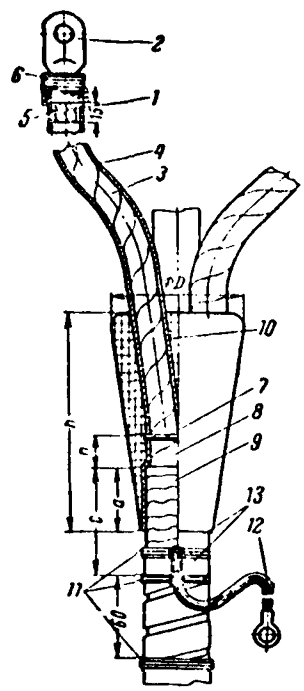

Fig. 11-2. The general view of the seal of cable from the epoxy trowelling compound. 1 - cable core; 2 - cap of the vein/strand; 3 - insulation of the vein/strand; 4 - three layers of winding from surgical tape with coating of each layer with the epoxy trowelling compound; 5 - supplementary winding of the vein/strand; 6 - binding from the twine; 7 - binding from the cotton fabric; 8 - zonal insulation of the cable; 9 - notch by knife on cable sheathing; 10 - the epoxy trowelling compound; 11 - binding wire; 12 - the grounding cable; 13 - soldering cable to shell and cable armature.

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11-2. Selection of cables.

Power cables select on design, on voltage and by economic current density and check against maximum prolonged current loads, on the loss of voltage during normal and emergency modes and on thermal resistance during short circuits.

The selection of cable on structural fulfillment, or, in other words, the selection of cable make-up, must be conducted taking into account the designation/purpose of cable and method of its separator. In this case they must be taken into consideration: a number and a material of core, the kind of insulation, construction/design of shielding deposits and other special features/peculiarities of cable.

Selection of cable on voltage. Cables reliably work with the voltage, which exceeds their nominal voltage on 15o/o. Since the maximum working voltage of electrical plants exceeds their nominal voltage not more as on 5-10o/o (see §3-1), then when selecting of cable on voltage is sufficient to observe the condition:

$$U_{\text{каб.ном}} \geqslant U_{\text{уст.ном}}, \qquad (11\text{-}1)$$

where $U_{\text{каб.ном}}$ - nominal voltage of the cable;

$U_{уст.ном}$ - nominal voltage of the installation, numerically equal to nominal line voltage, which feeds from this installation (see Chapter 3).

Selection of the section of cable on economic current density. On the basis of the considerations, analogous presented into §10-2 in the relation to of bare wires and busbars, TU MES of the USSR are established/installed the led in PUE [3-6] maximum economic current densities $j_{эк}$ for power cables and insulated wires (Tables 11-1), using which should be determined the sections of the cables:

$$s = \frac{I_н}{j_{эк}}, \qquad (11\text{-}2)$$

where $I_н$ - current of the greatest constant load of circuit in the normal mode of work (without taking into account possible in operation overloads of a circuit, and also increase of its load during emergencies and repairs).

The obtained condition (11-2) section they round off to nearest larger standard on Table P-11. With selected thus cable is provided the sufficiently high efficiency/cost-effectiveness of operation and the at the same time rational savings of means and nonferrous metal.

An economic number of cables before section 150 mm² is one cable. With s>150 the mm² an economic number of cables define as

s/150. In the interval between one cable 150 mm² and two cables on 150 mm² economically it is possible to consider also the version of two cables on 120 mm².

In electrical plants voltages above 1000 V the section of all cables should be determined, on the basis of economic current density, except the cables of temporary/time installations.

Checking cable to the maximum prolonged current of load (checking for heating in normal mode). According to the in force with the USSR norms for each cable is established/installed the maximum permissible under conditions for normal operation prolonged heating temperature of core $\theta_{доп}$, depending on insulation of core, construction/design and voltage of cable.

For some types of cables values $\theta_{доп}$ are shown in table P-11. The excess of this temperature leads to the quick aging of the insulation of cable, which is accompanied by a decrease in its dielectric strength, as a result of which are possible the breakdowns of insulation between veins/strands or between veins/strands and metal cable sheathings.

The long let-go current of the load of cable $I_{доп}$ is determined with maximum permissible prolonged temperature of its heating $\theta_{доп}$ and

at a specific calculated ambient temperature ϑ_0, taken for earth/ground of $\vartheta_0=15°C$ and for air of $\vartheta_0=25°C$.

Table 11-1. Maximum economic current density of power cables and insulated wires.

(2) Наименование проводников	(1) Предельная экономическая плотность тока $j_{эк}$, $а/мм^2$		
	(3) при продолжительности использования максимум. нагрузки $T_{макс}$, ч		
	(4) свыше 1 000 до 3 000	(4) свыше 3 000 до 5 000	(4) свыше 5 000 до 8 760
(5) Кабели с бумажной и провода с резиновой изоляцией с жилами:			
а) медными	3,0	2,5	2,0
б) алюминиевыми . .	1,6	1,4	1,2
(6) Кабели с резиновой изоляцией и медными жилами	3,5	3,1	2,7

Key: (1). Maximum economic current density $j_{эк}$ A/mm². (2). Designation of conductors. (3). with demand time of load peak T_{max} h. (4). it is more than 1000 to 3000. (5). Cables from paper and rubber-covered wire with veins/strands: a) copper; b) aluminum. (6). India-rubber cables and copper veins/strands.

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In Table P-11 are given the long let-go currents of the loads of the cables of different types, voltages and sections under the different conditions of separator. The permissible loads of the cables of other types (for example, with impoverished-saturated insulation) and with other methods of separator (in water, in blocks) are given in [3-6].

It is obvious that the section of cable, selected on economic current density, must be such so that with the maximum prolonged current of the load of that circuit, for which is intended the cable, the heating temperature of its veins/strands would not exceed $\vartheta_{доп}$. For this must be observed the condition:

$$I_{доп} \geqslant I_{н.макс}, \qquad (11\text{-}3)$$

where $I_{доп}$ - the long let-go current of load on cable (on table P-11);

$I_{н.макс}$ - maximum prolonged current of the load of that circuit, for which is selected the cable.

If condition (11-3) is not satisfied for the cable, selected on economic current density, then should be selected the cable of the larger section, which satisfies this condition.

When under the conditions of operation is possible the prolonged overloading of circuit, for which is intended the cable, then current $I_{н.макс}$ should be determined taking into account this overloading (see the appropriate indications in §10-2). In this case, if the greatest constant load in normal mode $I_{н}$ of paper-insulated cable by voltage

10 kV and does not exceed below 80o/o of its long let-go current $I_{доп}$, then during emergency mode in installation it is possible to allow/assume short-term overload of cable to 130o/o on the period of load peak during five days [3-6].

Table P-11.1 are given the long permissible loads of cables on the voltages 1-10 kV with paper insulation, run in trench (in the earth/ground), moreover as standard conditions of laying of these cables they are accepted: 1) cable runs itself one in normal earth trench at temperature of earth/ground of 15°C and 2) the depth of the laying of cable in trench from the earth's surface to cable sheathing not less than 0.7 m for cables to 10 kV and not less than 1 m for cables 20-35 kV.

If in trench they run several cables with clearance 100-300 mm, then as a result of deterioration in cooling conditions the permissible load on cable must be reduced in accordance with coefficient $k_ч$, taken on table P-11.5. Reserve cables considered must not be. In this case under reserve cables are understood also the normally working underloaded cables with cutoff/disconnection of which is possible the transmission on the remaining in work cables of entire rated power.

If the real temperature of the earth/ground in the place of

cable laying, equal to the average/mean monthly temperature of the earth/ground at the depth of cable laying in hottest month, differs from calculation, i.e., in terms of 15°C, then the permissible load of cable should be changed, taking into account correction factor k_T in table P-11.6.

In the case of cable laying to stony or dry sand soil the permissible load they decrease approximately/exemplarily to 15-25o/o depending on the thermal resistance of soil [9-2].

For the cables, laid in air, the long permissible loads (table P-11.2) are accepted for clearances between cables with the separator of them inside, also, out of buildings and in tunnels not less than 25 mm and in channels not less than 50 mm at any number of laid cables and temperature of air of 25°C.

If the real temperature of air in the place of cable laying differs from calculated, equal to 25°C, then the permissible load of cable should be determined with consideration correction factor k_T in table P-11.6. In this case by the temperature of air should be understood: out of premises the greatest average/mean diurnal temperature for this region, repeating not less than three times the year; indoors - greatest average/mean diurnal temperature in the place of cable laying.

In the case of cable laying under different conditions, for example, partially in air and partially in the earth/ground, the permissible constant load on cable should be accepted on the section of route with the worse conditions for cooling, if the length of this section is more than 10 m. In the latter case in section with the worse conditions for cooling it is possible to apply the cable inserts of larger section [3-6].

On the conditions of mounting and the cost/value of cable lines one should not apply the cables of too large cross sections. Are been commonly used triple-cores cable by section to 150-185 mm² and less frequently than large cross sections.

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It is necessary to keep in mind that the cables of large cross sections allow/assume less current density, which causes the overexpenditure of metal. The advisability of the separator of several cables of the smaller section instead of one cable of larger section is solved on the base of the technical-economic calculations, taking into account the cost/value of cables and their separator, operating costs and consumption of nonferrous metal.

Let us note that under emergency conditions can be allowed following short-term (by duration not more than 2 h) overloads of cables:

cables to 3 kV inclusively ... 10o/o.

cables 6-10 kV ... 15o/o.

The overloading of cables by voltage 20 kV and is not above allowed/assumed [3-2].

Checking cable to the loss of voltage is conducted by the execution of the electrical calculation of electric system for the purpose of the determination of the admissibility of voltage errors in the receivers of electric power in different modes of its operation [7-1]. Proceeding their established/installed by PUE values of the permissible losses and voltage errors, can prove to be necessary the use/application of a cable of the large section, rather than this was accept according to the conditions of the economic current density or heating in normal mode.

The cables of small length on electrical stations and

substations, for example cables to the generators, step-up and to step-down transformers, etc., of loss voltage do not usually check.

Checking cable to thermal resistance by short circuits is conducted in accordance with indications, data into §7-2. There it is shown, what cables it is possible against thermal resistance not to check.

The cables of small length without the couplings should be checked against thermal resistance during short circuit in the beginning of cable, it is direct after end preparing. If the sections of the cables of the single line of the large length, which has the couplings, are determined from the condition for thermal resistance during short circuit, then should be checked against thermal resistance each section of cable during short circuit in the beginning of this section, in this case is allowed/assumed the decrease by the steps/stages of the section of the cables of line over its length.

In the case of two and more parallel cables one should to proceed from short circuit directly the bundled cables, i.e., to consider that short-circuit current it is direct after bundled cables, i.e., consider that the short-circuit current branches on all in parallel to connected cables [3-6].

Example of 11-1. To select cable with aluminum veins/strands in the circuit of the line of setting, data which are given in example of 10-1. Cable runs itself in normal earth trench at temperature of earth/ground of ϑ_0=10°C. In one trench are laid the cables for the feed of two substations, analogous indicated in the diagram of Fig. 8-3b.

Selection of cable on design and on voltage. For a separator in the earth/ground we select three-core cable with aluminum veins/strands, with the paper saturated insulation, in general/common/total lead covering, armored by two flat/plane steel tapes, to nominal voltage 10 kV. Cable make-up ASB.

Selection of the section of cable on economic current density. On Table 11-1 with $T_{макс}=4000$ h we accept $j_{эк}=1{,}4$ A/mm². With $I_н=167$ A

$$s=\frac{167}{1{,}4}=119\ мм^2.$$

On data of table P 11.1 it is possible to select cable by section 3x120 mm² with $I_{доп}=240$ A.

Checking cable to the maximum prolonged current of load. From example of 10-1 it is known that $I_{н.макс}=334$ A. Consequently, the cable, selected on economic current density, this condition does not

satisfy. It is necessary to select the cable of larger section.

The cable of the nearest large section 3x150 mm^2 allows/assumes the current of load 275 A which is also less than the maximum current of the load of line. Cables by section more than 3x150 mm^2 are insufficiently economical; therefore it is expedient to fulfill line by two parallel cables of smaller section, calculated for constant load by the current, equal to $I_{н.макс}=334$ A.

In this case in one trench will be laid only 8 cables. However, since according to the condition for the work of network accepted on the diagram in Fig. in 8-3b cables in normal mode are loaded only half, then correction factor to a number of cables in trench it is necessary to accept from calculation four cables. On table P-11.5 with clearance between cables 100 mm we accept $k_ч=0.8$.

Correction factor to the temperature of soil of $\vartheta_0=10°C$ on table P -11.6 when $\vartheta_{доп}=60°C$ (permissible temperature of cable core 10 kV) comprises $k_т=1.06$.

General/common/total correction factor $k=k_чk_т=0.8\times$ of 1.06~~0.85.

If we take two cables by the section 3x70 of the mm^2 each of

which with normal separator allows/assumes current $I_{доп}=165$ A then with consideration correction factor they can be loaded to current not more: $I'_{доп}=2kI_{доп}=2\cdot 0{,}85\cdot 165\approx 280$ a, which is less $I_{н.макс}=334$ A. Therefore these cables cannot be accepted to separator.

We select two cables by section 3x95 mm² with $I_{доп}=205$ A. With consideration correction factor it is possible to load them to the current: $I'_{доп}=2\cdot 0{,}85\cdot 205\approx 350$ A, which is more than $I_{н.макс}$.

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Checking cables to thermal resistance. Parallel cables must be, as noted above, checked on short-circuit current after bundle of cables, i.e., on short at point K on the busbars of network substation (Fig. 8-3b). If the length of cables is small, on short-circuit current on supply-line substation little it differs from short-circuit current in the beginning of the waste/exiting line (only due to the resistor/resistance of the cables of the latter). Let us assume that precisely this case occurs in our example. Then the thermal resistance of cables it is possible to check in terms of the same values of short-circuit current which were accepted in example of 10-1 for testing the stability of busbars. In that example it was substantiated, that in thermal sense is more dangerous the two-phase short circuit. It is obvious that this to equal degree is

related also to cables. Therefore, utilizing data and results of calculations in example of 10-1, let us accept: $I_{\infty}^{(2)}=16{,}5$ kA and $t_{\phi}=1{,}5$ s.

Since $I_{н.макс}=331$ A little differs from $I'_{доп}=350$ A, then we count the temperature of cable core to short circuit $\vartheta_{н}=\vartheta_{доп}=60°$ C.

On curve for aluminum in Fig. 7-7 when $\vartheta_{н}=60°$ C we find $A_{н}\approx 0{,}45\cdot 10^{4}$. Then $A_{к}=A_{н}+\left(\frac{I_{\infty}}{s}\right)^{2}t_{\phi}=0{,}45\times 10^{4}+\left(\frac{16\,500}{2\cdot 95}\right)^{2}1{,}5=1{,}6\cdot 10^{4}$ and $\vartheta_{к}\approx 240°$ C, which is more than $\vartheta_{к\ макс}=200°$ C for cables with aluminum veins/strands. Thus, two cables by section 3x95 mm² are thermally unstable.

Let us select two cables by section 3x120 mm² with $I_{доп}=240$ A. With consideration correction factor these cables can be loaded to the current: $I'_{доп}=2\cdot 0{,}85\cdot 240\approx 408$ A.

Temperature of cable core to short circuit according to formula (7-16) $\vartheta_{H}=10+(60-10)\left(\frac{334}{408}\right)^{2}=45°$C. Through the curve of Figure 7-7 we find $A_{H}=0.35\cdot 10^{4}$, then $A_{к}=0{,}35\cdot 10^{4}+\left(\frac{16\,500}{2\cdot 120}\right)^{2}1.5\approx 1.05\cdot 10^{4}$ and ϑ_{K} 150°C, which for aluminum cables is admissible. Thus, we fulfill line by two parallel cables of brand ASB with a section of 3x120 mm^{2} each.

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Chapter 12

Electrical Contacts.

12-1. General Information.

In busbar/tire constructions/designs and electrical apparatuses and machines there is a large number of the electrical contacts, from the quality of execution and state of which to a considerable degree depends the reliability of the operation of electrical equipment and electrical devices as a whole. The damages of electrical contacts are frequently the reason for heavy emergencies in electrical devices.

Electrical contact is called the place of the contact of two or several conductors between themselves, through which flows/occurs/lasts the current of one circuit into another. At the same time in practice accept by electrical contact (or in abbreviated form by contact) to call also the contact connection, which is structural node, which consists of the contacting conductors and their connecting parts: bolts, rivets, contact springs, terminals/grippers, etc. In the disconnecting apparatuses by contacts accept to call each of the contacting conductors of contact connection (with all relating to it parts - contact springs, etc.).

For example, in knife switch distinguish slide contact, i.e., its knife, and fixed contacts into which throws in itself the knife upon the inclusion/connection of knife switch. Subsequently the term "contact" is utilized in all values indicated, about which it is necessary to judge by the sense of the set-forth material.

By conditions the works distinguish three fundamental means of the contacts: 1) rigid or motionless, 2) slipping (current collecting) and 3) breaking.

With solid contact the combinable current-carrying parts remain motionless one in relation to another, i.e., of mutual displacement is excluded. Such contact connections of wires and busbars, branching from them and their connection to the terminals/grippers of electrical machines and apparatuses.

In slipping contact one or both of the connected current-carrying parts can be moved by one with respect to another with the retention/preservation/maintaining of their mutual pressure, realized with the aid of springs.

The broken contacts are applied in the disconnecting apparatuses where they serve for closing/shorting and interrupting the circuit.

The quality of contact to a considerable degree is characterized by its electrical resistance, since on the value of the latter depends heating contact in nominal mode/conditions and with the course of short-circuit current. Extreme overheating of contacts can bring and to their decomposition and serious emergency.

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The examination of the contact of two well processed and matched to each other plane contacts shows that in actuality the contacts are contacted not all over contact surface, but only in a small number of points. Is explained this fact that on even very thoroughly processed metallic contact surfaces always remain very small projections and pockets, as this in the strongly exaggerated form shown in Fig. 12-1. in the absence of the force or pressure area contacts usually are contacted at one - three points, depending on their construction/design (from that, how freely they can be established/installed one relative to another).

Let us assume that during imposition the contacts were contacted only at one point. If we press such contacts by certain force F_1, then the apex/vertex of protuberances/prominences, on which they are contacted, somewhat will be rumpled and is formed the small area/site a of the real contact of contacts (Fig. 12-1a). An increase in the

compressive force leads to an even larger warping of protuberances/prominences a, to the approach of contacts and the onset of the contact of other protuberances/prominences, i.e., to the formation/education of the new supplementary areas/sites of contact, for example b (Fig. 12-1b). Thus, the real contact area of contacts, equal to the sum of the elementary areas/sites of contact, it is very small many times of less than their contact ("seeming") surface. Let us agree that subsequently we frequently will speak about the points of contact of contacts, implying by them not points in mathematical sense, but the surface elements of contact.

Experimentally was established/installed, that the real contact area of contacts does not depend on their sizes/dimensions and is determined by the force, which compresses contacts, and by temporary/time bearing resistance of the metal of contacts, that it is possible to express by the formula:

$$s=\frac{F}{\sigma_{\text{см}}}, \qquad (12\text{-}1)$$

where s - a real contact area of contacts, mm^2;

F - force of the pressure of contacts, kgf;

$\sigma_{\text{см}}$ - temporary/time bearing resistance of metal, kg/mm^2, that comprises: for copper 39-52 kg/mm^2, for aluminum 90 kg/mm^2, for

silver - 31 kgf/mm³.

One and the same contact area of contacts can be obtained with different sizes/dimensions of contacts only due to change in force of F.

The nature of the electrical resistance of contact connection can be clarified from the examination of the shown in Fig. 12-1 course of current in contacts with the limited number of areas/sites of contact. The electrical resistance of the unoxidized contact connection in essence is caused by the strong contraction of the path of the course of current in immediate proximity to the places of transition/junction from one contact to another as a result of small sizes/dimensions of the areas/sites, through which flows/occurs/lasts the current. Manifests itself also an increase in the mean pathlength of current. Based on this, the resistor/resistance contact connection $r_к$ can be examined by that consisting of two parts [12-1 and 12-2]:

$$r_к = r_п + r_м, \qquad (12\text{-}2)$$

where $r_п$ - contact resistance of contact connection, i.e., resistor/resistance in the place of the transition/junction of current with one contact to another;

$r_м$ - resistor/resistance of the metal of contacts, determined in

the section where is observed an increase in the current density.

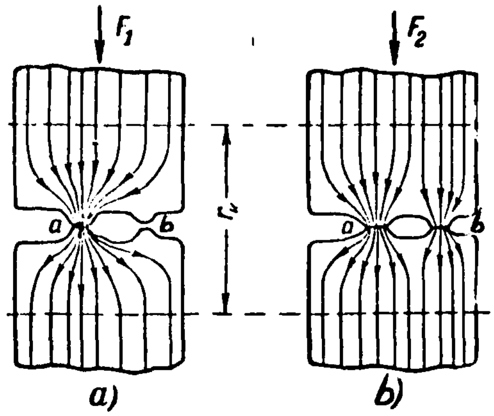

Fig. 12-1. Contact of two contact surfaces under the different forces of pressure ($F_2 > F_1$).

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Transient resistance $r_п$ of contact connection is caused by a small cross-sectional area of those flanges through which the current flows/occurs/lasts from one contact to another. If we for simplicity to assume that the contacting flanges of contacts have a form of cylinders with a diameter of d (cm) at negligibly low altitude, then contact resistance of the unoxidized single-point contact (Fig. 12-1a) can be determined by formula [12-2]:

$$r_п = \frac{\rho}{d}, \qquad (12\text{-}3)$$

where ρ - the resistivity of the metal of contact, Ω•cm.

Utilizing formula (12-1), it is possible to write the following expression for the area of the contact of contacts $s=\frac{\pi d^2}{4}=\frac{F}{\sigma_{cм}}$, hence $d=2\sqrt{\frac{F}{\pi\sigma_{cм}}}$. After substituting this value of diameter into formula (12-3), we obtain:

$$r_n=\frac{\rho\sqrt{\pi\sigma_{cм}}}{2}\frac{1}{\sqrt{F}}=\frac{k_1}{F^{0.5}}, \qquad (12\text{-}4)$$

where

$$k_1=\frac{\rho\sqrt{\pi\sigma_{cм}}}{2}.$$

Thus, contact resistance of single-point contact depends on the material from which it is made (ρ and $\sigma_{cм}$) also, from the force of the pressure of contacts (F).

Contact resistance of multipoint contact approximately can be determined by the analogous formula:

$$r_n=\frac{k}{F^m}, \qquad (12\text{-}5)$$

where the exponent m depends on the form of contacts and, mainly, from a number of points of their contact: for the single-point contacts m=0.5, for the the multi-exact m=1. In the latter case coefficient k depends not only on ρ and $\sigma_{cм}$, but to a considerable degree and from the method of the treatment of contact surfaces. For example, with ground contact surface contact resistance is more, rather than with the rough surface, cleaned by emery cloth, since in

the second case a number of points of contact of tangency is more.

For the approximate estimate of contact resistance according to formula (12-5) it is possible to take the following values of coefficient of k with the pure/clean, unoxidized contacts:

copper ... $(0.7-1.4)\cdot 10^{-4}$.

aluminum ... $(1.3-1.6)\cdot 10^{-4}$.

steel ... $(75-80)\cdot 10^{-4}$.

silver ... $(0.5-0.6)\cdot 10^{-4}$.

aluminum - copper ... $\sim 10\cdot 10^{-4}$.

steel - copper ... $\sim 30\cdot 10^{-4}$.

the approximate values of coefficient of m for the contacts:

plane - plane, multiplate brush - plane ... 1.

bolt busbar/tire contacts ... 0.5-0.7.

point - plane, sphere - plane, sphere - sphere ... 0.5.

With an increase in heating contact transition resistor/resistance increases as a result of increase ρ.

The surfaces of copper ones, aluminum, steel, etc. of contacts are oxidized by atmospheric oxygen. The films of oxide of the metals even very small thickness possess high electrical resistance, in consequence of which contact resistance of the oxidized contacts usually many times exceeds that determined according to the given higher approximation formulas. Especially intense oxidation is observed at a temperature of heating contacts of higher than 70-75°C. The measures of fight with the oxidation of contacts are presented further.

The contacts, placed into oil, are oxidized considerably less, rather than the contacts, which work in air.

Returning to formula (12-2), necessary to note that the resistor/resistance of the metal of contact $r_м$ in general small and has the vital importance only during the determination of contact resistance with low contact resistance $r_п$. when $r_п$ and $r_м$ are commensurated. Such contacts include the rigid bolted joints of busbars and wires, fulfilled with the large force of pressure, which

reaches hundred kilograms. In contrast to this in the slipping and opening contacts of the disconnecting apparatuses the force of pressure, created by contact springs, is considerably less; therefore they possess comparatively high contact resistance $r_{к} > r_{н}$. For these contacts it is possible to accept $r_{к} \approx r_{н}$.

To all electrical contact connections present the following fundamental requirements: 1) the reliability of the fulfillment; 2) durability against the external agencies; 3) the constancy of contact resistance; 4) heating in the permissible limits even 5) electrodynamic and thermal resistance with the course of short-circuit current.

With the course of the current of load in contact connection is separated/liberated the heat, especially considerable in the places of the real contact of contacts, proportional $I_{н}^{2} r_{к}$.

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For the heat removal from the places of the contact of contacts and for its scattering into the environment it is necessary that the contacts would possess the specific mass and cooling surface.

The maximum permissible temperatures of heating contacts with

the prolonged course of the current of load are established/installed by GOST [ГОСТ - All-union State Standard] 8024-56 and are from 75 to 100°C depending on their designation/purpose, construction/design, metal and safety method from oxidation.

Short-circuit current, flowing/occurring/lasting through contacts, creates the considerable effort/force, which attempts to move apart contacts, which is clearly evident from Fig. 12-1 (different direction of flow in contacts). The decrease of the force of pressure during short circuit causes an increase in contact resistance and the intensive heating of contact.

From entire that presented it follows that the sizes/dimensions of contacts are determined from the conditions for their cooling in normal mode, the guarantee of thermal and electrodynamic stability with the course of short-circuit currents. The sizes/dimensions of the broken and slipping contacts of the disconnecting apparatuses are determined also from the considerations of their mechanical strength with the fulfillment of process/operations, and to a certain extent and from design considerations.

12-2. Rigid (motionless) contacts.

The rigid (motionless) contact compounds include the connections

of wires and busbars, branching from them and their connection to the terminals/grippers of electrical machines and apparatuses. These contacts must satisfy the general requirements, presented in the preceding/previous paragraph.

The connection of busbars and wires and branching from them is fulfilled by welding, pressure (pressing), also, with the aid of bolts. The connections of busbars and wires to the terminals/grippers of electrical machines, apparatuses and instruments fulfill only with the aid of bolts, i.e., by split ones.

Welding busbars. With the aid of electrical or torch welding it is possible to connect copper, aluminum and steel busbars, and also copper busbars with aluminum ones. The connection of busbars by welding is very reliable, simply, cheaply and considerably accelerates the installation of busbar/tire construction/design. Because of butt welding and absence of tightening bolts substantially decrease of expenditure of metal and energy loss in fastening material - it is calculated, which in one tightening steel bolt of busbar/tire construction/design yearly is lost to 10 kW•h electric power [12-3]. Very important is the constancy of contact resistance of bonded contact, since is eliminated oxidation by air of contact surfaces. Therefore bonded contacts do not require permanent supervision in operation. Especially they are convenient in those

constructions/designs of the distributors where this supervision is generally difficult, for example, with the execution of distributors in metallic cabinets (the so-called cubic switchboards - see Vol. Chapter 9.

Fig. 12-2a shows connection by welding two rectangular busbars 1. Gap 2 between the ends/faces of busbars, the width of joint 3 and weld reinforcement 4 depend on sizes/dimensions and material of combinable busbars [12-4]. Certain thickening of the joint of welding provides the mechanical strength of bonded contact. As the added material, which forms the joint of welding, are utilized the rods of the material of the joined busbars (with connection copper - aluminum applies aluminum).

Welding points tincture with the same paint, as busbar.

With technical control MES it is recommended [12-5] to use extensively welding collecting mains and branchings from them. In this case the attachment of stand-off insulators must be carried out so that it would be possible to change them without cutting of the welded busbars.

The connection of rectangular busbars with pressure (pressure welding) is based on the property of metals to diffuse into each

other under the action of large pressure, in resulting the metals are poured into monolithic (homogeneous) mass.

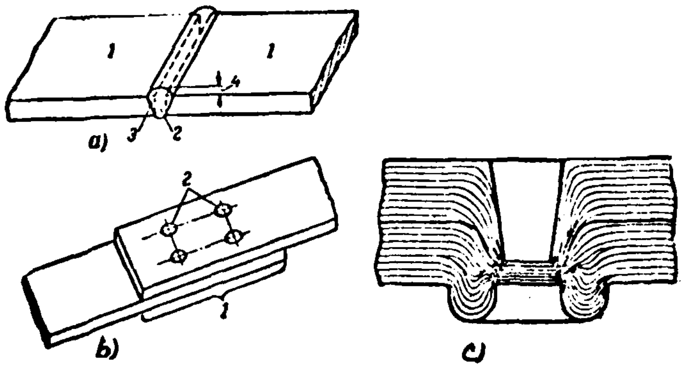

Fig. 12-2. Connection of rectangular busbars.

a) by the welding; b and c) by pressure.

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Connection is fulfilled overlapping (Fig. 12-2b), the length of overlapping 1 and a number place of the depression of 2 metals depend on the sizes/dimensions of the combinable busbars. The depression of the metal of busbars is fulfilled on special hydropress with the aid of punches. Before the connection the prepared surfaces of busbars must be purified from the film of oxide and grease.

For protection from oxidation the points of connection of busbars by pressure tincture with the same paint, as busbar. The points of connection of copper busbars with aluminum ones cover/coat with two layers of transparent glyptal varnish.

The connection of busbars by pressure possesses in essence the same merits as the connection of busbars by welding. It is recommended to apply it in all cases, except the execution of the sets of busbars of chains of generators, installations for their own needs, the cells of the transformers with a power of 20 MVA and more, and also installations subjected to vibration (taps/cranes, vessels,

etc.) [L. 12-6].

With the aid of special tongs/mites it is possible to also connect by pressure in joint single-wire wires. Such connections possess very low contact resistance and large mechanical strength.

Connection of rectangular busbars with the aid of bolts. Are distinguished two basic versions of this connection of the busbars: connection by through bolts (Fig. 12.3a, b and c) and connections with the aid of clamping cover plates (Fig. 12-3d and e).

By an essential deficiency/lack in the connection of busbars through bolts is the need for the preliminary careful marking of busbars, and then their drilling. With the lap joint of the axis of the joined busbars they do not coincide (Fig. 12-3a), for eliminating what if necessary one of the joined busbars must be bent (Fig. 12-3b). By butt joint with the aid of two (or one) cover plates (Fig. 12-3c) it is possible to avoid curvature of one indicated of the busbars, but due to considerable complication and rise in price of the connection: is more the expenditure of the busbars (cover plates make from the joined busbars), it is necessary to process large contact surface and to drill larger number of holes, is required more than bolts. Furthermore, with butt joint is more contact resistance and is less its stability during short circuits. Therefore the

connection of busbars in joint with the aid of through bolts to apply is not recommended.

The connection of busbars with the aid of clamping cover plates and bolts (Fig. 12-3d and e) is considerably simpler, since is not required markings and drillings of openings/apertures. Furthermore, this connection is characterized by smaller contact resistance and larger mechanical strength. With the operating currents of 600 A and is more necessary to apply cover plates or bolts from nonmagnetic material for an increase in resisting to magnetic flux and decrease of induction in the steel parts of connection, which leads to the decrease of heating from hysteresis and eddy currents of fasteners and, consequently, also contact.

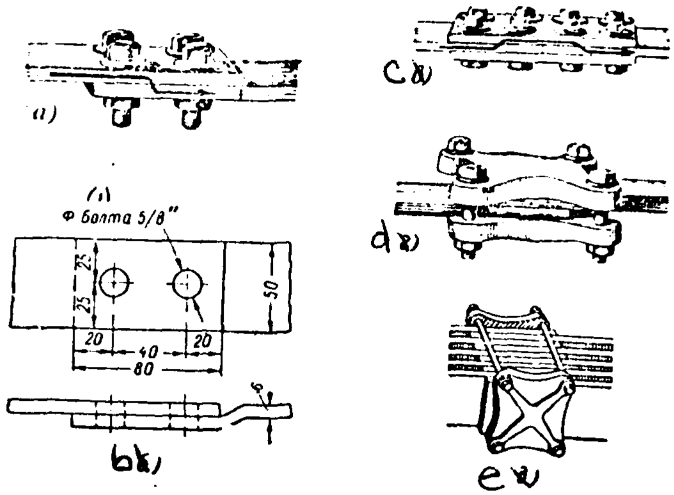

Fig. 12-3. Connection of rectangular busbars. a and b) by the overlapping through bolts; c) in joint by the through bolts; d and e) with the aid of clamping cover plates.

Key: (1). Bolt.

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A deficiency/lack in the bolted joints is the inconstancy of contact resistance which in the course of time increases, which leads to overheating of contact and further increase in its contact resistance. The fundamental reason for this is decrease of pressure in contact as a result of the change in the tightening of bolts, caused by different expansion during heating of aluminum or copper

busbars and steel bolts.

The oxidation of contact surfaces sharply increases contact resistance and heating of bolt contact. For eliminating the film of oxide is necessary the dismantling of contact, that is connected with the prolonged cutoff/disconnection to counterpart electrical device. In order to avoid this, it is necessary, in the first place, to fastening to thoroughly clean contact surfaces from the film of oxide and, to secondly protect bolt contacts from the subsequent oxidation in operation. The latter is reached by deposition on the contact surfaces of the metallic shielding anticorrosive coatings (layer of metal will be deposited in the molten state or galvanically) and by hermetically sealing/pressurizing/sealing the contact connections, which eliminates air inlet to the places of the contact of contacts.

Contacts from copper, brass and bronze frequently shield from oxidation by the thin layer of tin or alloy of tin and lead. Such tinplated contacts possess somewhat high contact resistance (to 30-50o/o) in comparison with resisting of pure/clean unoxidized contacts, but this is compensated by the fact that it does not grow/rise in the subsequent operation.

The tinplating of copper contacts is necessary in external installations, in the locations damp/crude, which contain reactive

gases, and at temperature of air of higher than 60°C. During mounting under the same conditions is necessary hermetic sealing/pressurization/sealing copper contacts, achieved by the twofold coating of the external contact surface and joints by transparent glyptal varnish.

Heavy-current copper contacts in external installations and in damp/crude locations it is expedient to shield by the anticorrosive film, superimposed galvanically. The best results gives silver plating of contacts, since silver in air is not oxidized, but it is covered/coated with the film of sulfide of silver (Ag_3S), the forming during the resolution of hydrogen sulfide air in the presence of oxygen. The conductivity of sulfide film is close to the conductivity of silver; therefore the covered with silver contacts do not change their properties.

Steel contacts in all cases should be tinned and hermetically sealed the dual layer of glyptal varnish.

Aluminum in air greatly intensely is oxidized during considerable resisting of the film of oxide. Therefore in all cases aluminum bolt contacts are fulfilled as follows. To the fastening of aluminum contact surfaces they clean under the layer of the petroleum jelly, which shields them from oxidation. Then the layer of

contaminated petroleum jelly is driven out and will be deposited the thin layer of pure/clean petroleum jelly. With fastening in the places of the real contact of contacts the petroleum jelly is extruded, but it remains in gap between contacts how is provided the airtightness of connection. So that in the process of work petroleum jelly would not ensue/escape/flow out, contact connection they twice cover/coat with glyptal varnish [1. 12-4].

To deficiencies/lacks in the bolted joints one should relate also the presence of energy losses in fasteners.

The terminals/grippers of electrical apparatuses, machines and transformers are fulfilled from copper or brass. Therefore in open distributive devices and in the damp/crude locations it cannot be of the aluminum ones of busbar directly connected by bolts to the terminals/grippers of apparatuses and machines. It is known that contacting copper (brass) and aluminum form the electrolytic pair, which possesses a potential difference, equal to 1.86 V (potential of copper in relation to hydrogen equals +0.52V, and of aluminum - -1.34 V). Therefore in the case where moisture containing disolved salt, i. e., being an electrolyte, penetrates to the copper - aluminum contact, local currents arise under the action of the indicated difference in potentials which cause an electrolytic reaction accompanied by intensive corrosion of the aluminum part of the contact. As a result of this, the contact is destroyed quickly, which may be the reason for serious damage. To prevent this, special

intermediate clamps consisting of welded aluminum and copper parts are employed in the indicated units to connect aluminum busses to copper (brass) clamps of apparatuses. An example can be provided by a copper-aluminum transition plate (on Fig. 12-4a) which is used when connecting an aluminum bus to a flat clamp of an apparatus.

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Sometimes, for the same purposes a copper plate is welded on an aluminum bus. The plate also comes in contact with the apparatus clamp (Fig. 12-4b). In all these cases, there are bolt connections of only copper with copper; therefore, corrosion of the busses does not occur.

The direct connection of aluminum buses to apparatus clamps with bolts is permitted in covered distributing devices. The copper transient plates (Fig. 12-4b) which are employed in these cases have another purpose - to reduce the contact resistance at the place where the bus is connected to the equipment clamp, which can have substantial significance with large operating currents.

The qualtity of a bolt contact can be judged from the value of its electrical resistance which at temperature of busbar of 70°C must not exceed to more than 20o/o resisting of whole section of busbar, equal to the length of contact connection, and according to its heating temperature which must not be more than the temperature of the whole section of busbar at a distance of 1.5-2 m from contact.

Everything said previously is related also to the execution of the branchings of busbars (Fig. 12-5).

Connection and branching of flexible stranded wires. Flexible stranded wires connect with the aid of the same terminals/grippers with reduction or by pressing as the wire of aerial lines [L. 7-1]. Branchings from patch cords and their connection to the terminals/grippers of apparatuses fulfill with the aid of the pressed terminals/grippers. A similar branch terminal is shown in Fig. 12-6a. Drive 1, from which is fulfilled the branching, they pass through tube with 2 and housing of 3 terminals/grippers. Wire branchings 5 introduce into tube 4 terminals/grippers. By the special press of tube with 2 and 4 press around wires how is created the reliable contact connection of wires with terminal/gripper.

Fig. 12-6b shows the pressed apparatus terminal/gripper. The tube of 7 terminals/grippers is pressed around wire 6. Plat/plane cap 8 with openings 9 serves for the connection by bolts to the terminal/gripper of apparatus.

The pressed terminals/grippers are very reliable; therefore recently them are used extensively during the mounting of patch cords

in the distributors of all voltages.

Earlier in distributors were applied bolt terminals/grippers. An example is given in Fig. 12-6c instrument room bolt terminal/gripper. Here wire 10 is jammed in the housing of 13 terminals/grippers with the aid of screw dies 11 and bolts 12. As with any bolted joint, the tightening of bolts in the course of time weakens, which leads to an increase in contact resistance and overheating of contact. As a rule, contact resistance of bolt clamps is always more than the terminals/grippers of those pressed. At present bolt terminals/grippers apply only as an exception in the absence of the pressed terminals/grippers as temporary/time [L. 12-4].

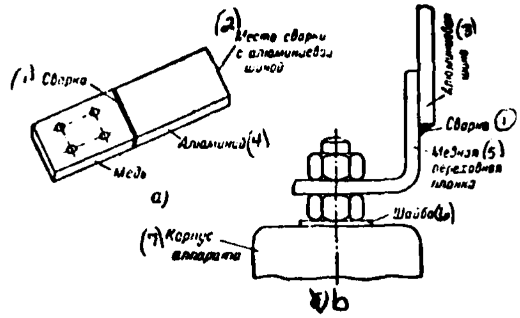

Fig. 12-4. Transient plates for the connection of aluminum busbars to the copper (brass) terminals/grippers of apparatuses.

Key: (1). Welding. (2). Welding point with aluminum busbar. (3). Aluminum busbar. (4). Aluminide. (5). Copper transient plank. (6). Washer. (7). Housing of apparatus.

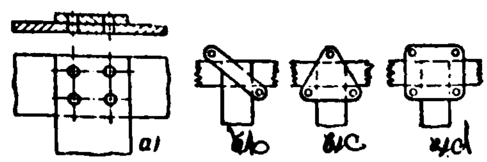

Fig. 12-5. Branching of rectangular busbars. a) by the overlapping through bolts; b, c and d) overlapping with the aid of clamping cover plates.

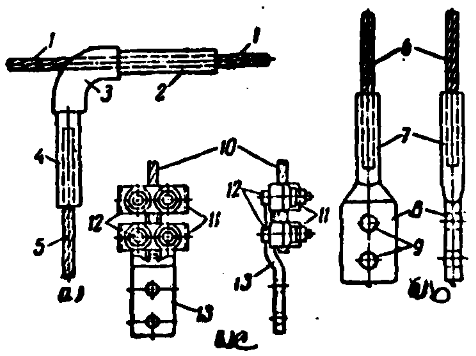

Fig. 12-6. Branching and apparatus terminals/grippers. a) branching pressed by clamp; b) apparatus pressed terminal/gripper; c) instrument room bolt terminal/gripper.

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Apparatus terminals/grippers for aluminum and steel-aluminum wires are fulfilled from aluminum, moreover on the flat/plane part of the terminal/gripper (8 in Fig. 12-6b) is a soldered copper plate, which is contacted with the terminal/gripper of apparatus.

12-3. Broken and slipping contacts.

The slipping contacts, and also those breaking contacts of the disconnecting apparatuses which are not intended for start and cutoff/disconnection of circuits for the current of load or short circuit (for example, the contacts of disconnectors or the make

contacts of those switches in which there are special arcing contacts, see further), they must satisfy the general requirements, presented in §12-1. Furthermore, they must possess sufficient mechanical strength, i.e., maintain/withstand the established/installed by norms number of process/operations.

The broken contacts must satisfy the following supplementary requirements:

1) with cutoff/disconnection for the current must not be of the excessive destruction of contacts their electrical another, that blocks further exact work;

2) upon the inclusion to the existing in network short circuit must not be of the destruction of contacts and their welding as a result of the course of short-circuit current.

In the slipping and broken contacts the necessary pressure in contact is provided by using the elasticity of contacts themselves or with the aid of steel contact springs.

The use of an elasticity of contacts themselves does not provide the constancy of the force of pressure, but thereby also the constancy of contact resistance. With starts and

cutoffs/disconnections elastic contacts somewhat are deformed, that also leads to the decrease pressure in contact. The considerable overheating of such contacts leads to the loss by them of elasticity (annealing of metal) and to a sharp increase in contact resistance. The special contact springs, not streamlined with current, provide more permanent pressure in contact.

The broken and slipping contacts most frequently are fulfilled from red copper or from brass. Such contacts, as has already been indicated, in air they are oxidized. In spite of small thickness (on the order of $25 \cdot 10^{-6}$ mm), the film of oxide possesses considerable electrical resistance. For the purpose of the decrease of the effect of oxidation on contact resistance construct the contacts, so that the interrupting and their closing/shorting would be accompanied by the slip (friction) of one contact on another. In this case the thin film of oxide breaks down itself and is driven out with the area of the real contact of contacts - occurs the self-purification of contacts. Than more the concentrated force of mutual pressure, the better the self-purification of contacts, the less contact resistance.

They recently widely practice silver plating of the contacts, which work in air. Frequently to copper contacts are welded on the silver strips, on which the contacts are contacted.

High value has the electrodynamic and thermal resistance of contacts with the course of short-circuit current. The destruction of insufficiently mechanically durable contacts under the action of electrodynamic forces with the course of impact short-circuit current entails, as a rule, considerable damage of apparatus, and in a number of cases and its full/total/complete destruction, which can be the reason for very serious emergency.

If contacts are controlled badly/poorly, i.e., if the real area of their contact is small, and contact resistance, therefore, is great, then with the course of short-circuit current is feasible the excessive overheating of contacts and their fusing in the places of real contact - contacts can be welded. It is understandable that the broken or slipping contacts cannot fulfill the entrusted on them functions.

Since contacts are contacted in the limited number of points, then, as noted above, between them appear the electrodynamic forces, which attempt to move aside one contact from another, what counteracts the external force, which presses contacts friend and to friend. The less a number of points of contact of the tangency of contacts and the greater the flowing current, the greater the

electrodynamic force indicated. With the badly/poorly controlled contacts with the course of impact short-circuit current this force can exceed the force of pressure in contacts and they can somewhat be radiated. In this case between them arises the arc, it is strong their fusing. The subsequent approach of contacts after reduction in current of short circuit leads to their welding.

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In many switches with the course of short-circuit current occurs interaction of current in their separate current-carrying parts, and also current in the latter with current in the supplying busbars. These electrodynamic efforts/forces also decrease the pressure in contact, result of which can be its overheating, fusing and welding.

For the purpose of increase in the stability of contacts with the course of short-circuit currents attempt to construct contacts so that the taking place on the current-carrying current elements of short circuit would create the supplementary effort/force, forcing contacts against each other. As the example of this construction/design can serve contacts, given in Fig. 12-9. Here fixed contacts are carried out in the form of T-shaped contact supports 1, which are encompassed by two-band slide contact 2, which rotates on axis 3. With course on the bands of the slide contact of

short-circuit current they mutually are attracted/tightened, than is provided an increase of the pressure in contact.

With the cutoff/disconnection of circuit for the current between the contacts of switch appears the electric arc. Since the temperature of the cathode spot composes approximately/exemplarily 1500°C and it considerably exceeds the melting points of the metals, generally accepted for contacts - copper (~1080°C), brass (~900°C), silver (~960°C), then under the action of arc occurs the partial fusing of the metal of contacts, which is accompanied by certain sputtering of metal and by its evaporation in arc.

Therefore, on possibility, contacts must be carried out so that the arc would not break down those working contact surfaces through which flows/occurs/lasts the current in the connected position of switch. The fusing of working contact surfaces leads to excessive increase in their contact resistance and overheating.

If the condition indicated is impracticable, and at the high values of rated current they also supply switches with two types of contacts - by worker and arc-suppression.

Make contacts are designed for prolonged flow of the current about the load with the connected switch and are not intended for the

disruption of arc. Through them flows/occurs/lasts the short-circuit current with the locked switch. Therefore make contacts must have least possible contact resistance. Their sizes/dimensions are determined from cooling conditions.

The arcing contacts, parallel to make contacts, are intended for the disruption of arc and are designed only for short-term flow of current in the process of the cutoff/disconnection of switch. In the connected position of the switch through arcing contacts flows/occurs/lasts only a small fraction of the current of load, since resisting of the outline of arcing contacts is always more than resisting of parallel circuit of make contacts.

About arcing contacts flow the considerable disconnected current (short-circuit current or current of load) it is only short-term in the process of the cutoff/disconnection of switch; therefore their sizes/dimensions are usually small in comparison with the sizes/dimensions of the make contacts of switch. At the same time arcing contacts pick up entire gravity of the disruption of arc, why they must be especially stable with respect to its destructive action.

In the presence of working and arcing contacts the movable system of switches is fulfilled so (Fig. 12-7), that with

cutoff/disconnection first diverge make contacts (2 and 3), and arc-suppression (5 and 6) for a while they remain still locked, and through them flows/occurs/lasts entire disconnected current. After the make contacts are radiated up to the sufficient distance, with which is already impossible the onset on them of arc, begins chain cleavage with the arcing contacts, on which is formed the arc. Upon the inclusion of switch the contacts are closed in reverse order.

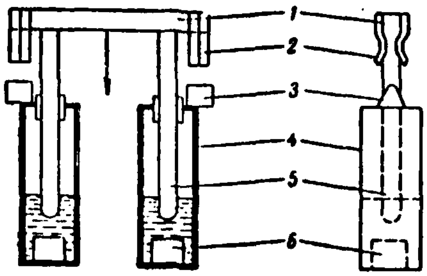

Fig. 12-7. Schematic of the working and arcing contacts of oil breaker with small space of oil. 1 - contact crosshead; 2 - movable make contacts; 3 - motionless make contacts; 4 - tank; 5 - movable arcing contacts; 6 - motionless arcing contacts.

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Thus are retained expensive and massive make contacts. The caps of arcing contacts in proportion to wear replace.

The disconnecting apparatuses, not intended for chain cleavage for current (for example, disconnectors), have only make contacts.

For the purpose the decreases of destruction of contacts under the action of electric arc in a number of cases fulfill arcing contacts or their caps of the refractory metals and the connections. Recommended well themselves cermet connections from silver or copper with tungsten or molybdenum. Connections made of silver and tungsten

are most advisable for the contacts, which work in air, while connections from copper and tungsten or copper and molybdenum - for the contacts, which work under oil. Tungsten or molybdenum give to ceramic metal hardness and high melting point (high arc resistance). Copper and silver give sufficiently high electrical conductivity.

Upon the slow inclusion of switch at the first moment of the contact of contacts the pressure between them in the place of contact can be small. If the included current is great, then in the place of initial contact of contacts is separated/liberated a large quantity of heat, and contacts strongly are fused; after the termination of start and cooling the contacts can be welded. Is especially great the danger of welding contacts during their slow approach in the case of the inclusion to the existing in network short circuit. For preventing this should be always more rapidly possible switched on the switch. The greater the rate of the motion of contacts, the less the danger of their welding.

Upon rapid start is unavoidable the impact of slide contact about motionless at the moment of their initial contact. In this case the contact, connected with spring, can bounce or begin to jar. The appearing short arcs fuse contacts, which can lead to their welding after the termination of start.

For the purpose of prevention this necessarily the specific pressure between contacts at the moment of their first contact. Is reached this by the appropriate tension of contact springs. In this case one should remember that if the insufficient pretensioning of contact springs can lead to bouncing of contacts at the moment of their initial contact, then excessive spring tension will increase the rigidity of start, and also the effort/force, necessary for the start of switch.

In operation the elasticity of contacts and springs, and also the tightening of the latter can change as a result of mechanical jolts with starts and cutoffs/disconnections also of the electrodynamic and thermal actions of short-circuit currents. As a result of this increases contact resistance and temperature of contacts. Therefore it is necessary to thoroughly follow so that the contacts tightly and with sufficient force would fit closely to each other, for which them they will periodically inspect and if necessary regulate and they pull springs.

Depending on form the broken and slipping contacts are contacted over surface (surface contact), along line (linear contact), also, at one point (point contact).

Surface contact can have the flat/plane or curvilinear

contacting surfaces. The surface contacts include the examined into §12-2 rigid (motionless) contact compounds.

In surface contact a number of points and sizes/dimensions of the real areas/sites of the contact of contacts are relatively small even under the large force of pressure in contact. With the bolt contacts possibly is achieved low contact resistance, in the first place, by applying several bolting, since each of them gives certain number of points of contact of tangency, and, in the second place, via the tightening of bolts by the considerable force, equal to several hundred kilograms to bolt.

The force of pressure in the broken and slipping contacts at best composes several ten kilograms, in consequence of which contact resistance of surface contacts proves to be considerable. An increase in the sizes/dimensions in the contacting surfaces does not bring, as is known, to a decrease in contact resistance; therefore for decreasing contact resistance are fulfilled surface contacts of several parallel contact elements/cells, equipped with the independent contact springs (it is similar to elements/cells 1 and 1' in Fig. 12-13).

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Than of a larger number of contact elements/cells consists surface contact, the less its contact resistance and thereby to larger operating current it can be carried out.

The least slant of one contact surface with respect to the other leads to a sharp decrease of a number of points of contact of tangency (in limit to one point) and an increase in transient resistance; therefore surface contacts require very careful control and attentive supervision in operation. In the best position prove to be the self-adjusting contacts, when one of the contacts can be established/installed freely relative to the other. Such contacts usually are contacted not less as at three points (Fig. 12-12b).

After each cutoff/disconnection and inclusion the surface contacts in practice are contacted at different points; therefore with process/operations with them badly/poorly is cleaned the film of oxide and contact resistance of them is very variably and in the process of operation is changed.

In the badly/poorly controlled surface contacts, which have a small number of points of contact of tangency, with the course of short-circuit current appear the very considerable electrodynamic forces, which attempt to finish harvesting contacts from each other. Contacts, and especially their spring must be calculated for these

forces, since otherwise they will be destroyed with the course of short-circuit current.

Surface contacts usually possess high thermal resistance, since the considerable mass of contacts provides good removal of the heat, which separates in the places of their contact.

Linear contact is formed with the contact of cylindrical surface with plane, with contact on the generatrix of two cylindrical surfaces and the like (Fig. 12-8e). Strictly speaking, linear contact is the very ridge on which are arranged/located real points of contact of tangency.

The applied to linear contact effort/force is distributed to a small contact surface how is reached large specific pressure in contact. Therefore with the same force of pressure a number of points of real contact in linear contact easily can be obtained in any case not less, but frequently also it is more than in surface contact.

If during closing/shorting and interrupting linear contact one of the contacts slips over the surface of another, then because of considerable specific pressure in contact the thin film of oxide of metal easily breaks down itself and is driven out from contact surface, as a result of which contact resistance of contact

decreases. Vital importance has that the fact that with linear contact is more is definitely fixed/recorded the area/site of contact.

Thus, linear contacts, as a rule, possess smaller and more permanent contact resistance in comparison with surface contacts. According to experimental data [1. 12-7], in the region of the comparatively small pressures which occur in the contacts of the disconnecting apparatuses other conditions being equal contact resistance of the copper linear contacts is 2-3 times less than surface ones.

With linear contacts also is considerably simpler their control, since to more easily ensure the correct contact of plane with cylinder, than two surfaces. For example, certain slant of contact support in Fig. 12-10 (it is shown by dotted line) does not disrupt linear contact.

In recent years in the disconnecting apparatuses of all voltages linear contacts to a considerable degree extruded/excluded the less ideal surface contacts.

Point contacts are formed with the contact of spherical surface and plane, two spherical surfaces, etc. In point contact the contact

in practice occurs in one area/site of very small sizes/dimensions. Point contact is characterized by large specific pressure and good fixation of the place of contact, which provides the constancy of contact resistance, especially if with process/operations hemisphere slips on the plane, i.e., if proceeds self-cleaning from the film of oxide of metal.

In point contacts is small the mass of the metal, adjacent directly to the surface area of contact. This makes the removal worse of the heat, which separates in the place of the transition/junction of current from one contact to another. Therefore point contacts are been commonly used with comparatively small both the operating currents and short-circuit currents (comparatively low thermal resistance).

By design are distinguished the contacts: springing, lamellar, finger/pin, socket, end-type and brush.

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The springy contacts are applied mainly in knife switches and safety devices/fuses; earlier them were applied also in disconnectors.

The simplest springy contact (Fig. 12-8a-c) in essence consists of the motionless springy contact supports 1 various forms and moving contact knife 2. Upon start the knife enters between contact springs, somewhat separating/expanding them, and it is fastenned between them. Pressure in contact provide the springy contact supports, prepared from sufficiently elastic material - to hard-drawn copper, brass or special bronze. For guaranteeing a larger number of points of contact of tangency with knife contact supports usually divide into several parts (Fig. 12-8c).

Deficiencies/lacks in these contacts they escape/ensue of that entire previously presented: the difficulty of control, inconstancy and significant magnitude of contact resistance, small stability during short circuits. With high contact resistance and in the course of short-circuit current the contacts can be heated to the temperature of the annealing of copper, after this the springs lose their elasticity and pressure in contact it decreases, which leads to even larger heating of contact.

To deficiencies/lacks in the similar contacts it is possible to also relate the considerable expenditure of metal for contact supports and impossibility of pressure adjustment in contact.

Somewhat best is the contact, given in Fig. 12-8d, in which is

provided supplementary steel spring 3, which ensures more constant pressure in contact.

In the apparatuses, manufactured at present, the springy contacts usually are fulfilled with linear contact. For this either on the bands of knife or on contact supports stamp out the semicylindrical flanges, which create linear contact. As an example Fig. 12-8e shows this contact, equipped with strong ring spring 4. Spring is not the current-carrying element/cell of contact; therefore its annealing and loss by it of elasticity little are probable, thanks to which is provided constant pressure in contact. The advantages of linear contact were discussed above. The contacts of this construction/design are applied in the new Soviet safety devices/fuses of low voltage of the type PN2 (Fig. 14-7) and in the new constructions/designs of knife switches.

Lamellar contacts are used extensively in knife switches and disconnectors for internal intallations. Fig. 12-9 shows the simplest lamellar contact with contact on the plane. Fixed contacts are carried out in the form of T-shaped contact supports 1, which are encompassed by the bands of 2 slide contacts, which rotates on axis 3. Bands 2 are pressed against suppport by steel helical springs 6. At this construction/design is reached considerable metal savings and is provided more constant pressure in contact in comparison with the

spriagy contacts. Springs 6 are not the current-carrying elements/cells of contact, why their annealing and loss by them of elasticity are scarcely probable. Pressure in contact is easily regulated by a change in the tightening of springs (by nuts 5).

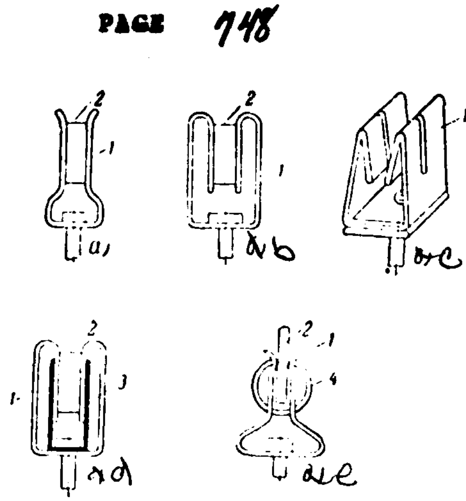

Fig. 12-8. Springy contacts.

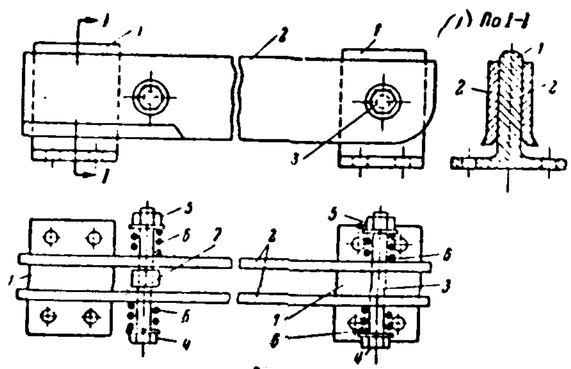

Fig. 12-9. Lamellar area contacts. 1 - T-shaped contact supports; 2 - band of the slide contact; 3 - rotational axis of the bands; 4 - bolts; 5 - nut; 6 - spring; 7 - the spacer.

Key: (1). On.

Characteristic feature is also large stability during short circuits, since with the course of short-circuit current bands are attracted/tightened to each other.

The deficiencies/lacks, inherent in surface contacts, were shown above. Their use/application for the disruption of arc is undesirable, since under action the arcs of plane strongly are fused, that makes even without that the insufficiently reliable contact worse.

More advanced is the lamellar linear contact, given in Fig. 12-10.

Contact consists of T-shaped support 2, which is encompassed by the bands of 1 slide contact. These bands have stamped/die-forged spigots 3, which are contacted with contact stable along lines. Pressure in contact is created by steel springy clamp 4.

Linear contacts must not be utilized as arc-suppression ones, since under the action of electric arc they badly break down themselves.

Knife switches with lamellar surface and linear contacts usually have the supplementary arc-suppression caps of various forms from

brass or carbon/coal (see for example, Fig. 15-2).

A deficiency/lack in the contacts on Fig. 12-9 and 12-10 is a small distance between the bands of slide contact, which impedes their determination to motionless contact support. Even during the smal displacement of slide contact upon start plates are struck against end of support, which impedes start. For eliminating this they sometimes separate several to the sides of the edge of the bands of slide contact (in the part, which adjoins the support) as that it is shown in fig 12-9.

There is no this deficiency/lack does not have the lamellar linear contact, given in Fig. 12-11. With such contacts are at present supplied Soviet disconnectors for internal installation to 6-10 kV and rated currents to 600 A (types RV and RVO - see chapter 16). Contact supports 1 and 2 are made from those bent at the right angle of the copper bands which are encompassed by the bands of knife 3. The lateral surfaces of supports are rounded (which is not compulsory) how is provided contact along line (narrow surface). The plates of knife are pressed against supports by springs 4, put on to rods 5. Distance tube with 6 limits the approach of the band of knife in off position. Knife rotates on axis 7, attached in bearing 8. The considerable distance between bands 3 and the rounding of the upper part of support 1 lightens the determination to it of bands upon

start.

Contacts are equipped with forceps type magnetic lock, which consists of two steel plates 9, put on to rods 5. On other ends of these plates are grooves 10, entering the turnings of rod 11 and axis 7. The current, flowing on the plates of knife, creates th magnetic flux which is closed on steel plates and air gap between them. Power flux lines attempt to decrease their length and in this case to draw together the plates between themselves.

Plates 9 are carried out in the form of levers of the second kind; therefore the force, which forces the plate of knife against support, is determined from condition (Fig. 12-11): $F_1=F(b/a)$, where F - the resulting magnetic force, which operates on the plate of lock. With the aid of forceps type magnetic locks it is possible to obtain very large supplementary pressures in contacts with the course of impact short-circuit current, which raises the electrodynamic stability of contacts.

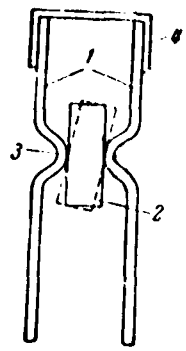

Fig. 12-10. Lamellar linear contacts.

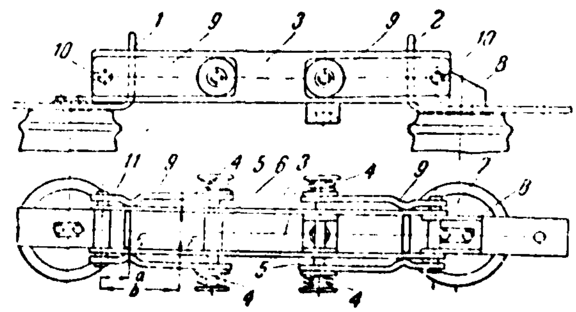

Fig. 12-11. Contacts of disconnectors 6-10 kV to rated currents to 600 A (disconnectors of types RV and RVO for internal installations).

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Pin contacts (Fig. 12-12) are nonself-adjusting a and self-adjusting b. In bot constructions/designs contact brass fingers/pins 2 are attached on flexible current-carrying plates 3, which consist of the series/row of thin copper plates. Fingers/pins 2 are pressed against tapered contact knife 1 (brass, red copper) with

the aid of flat/plane steel springs 4 and 5. Plates 3 and springs 4 and 5 by bolted to rectangular current-carrying block 6 (contact holder).

Moving element/cell in pin cortacts it can be both knife 1 and pin contacts themselves (knif is fixed).

In the nonself-adjusting contacts (Fig. 12-12a) contact pins 2 and plates 3 rigidly (by aid of rivets) are fastened with spring 4. Therefore the contact pin cannot freely be adjusted by its plane on the plane of the knife; the contact of finger/pin and knife occurs usually in a small number of points (frequently at one-two points).

In the self-adjusting pin contacts (Fig. 12-12b) springs 4 are not attached to fingers/pins 2, but they press on the through hemispheric surface of 7 on the contact pin. Therefore the finger/pin can be turned and freely be superimposed on the surface of the contact knife: the contact of finger/pin and knife occurs in a larger number of points. Clamps 8 block the displacement of fingers/pins upward, also, to sides with cutting between them of contact knife.

With the course of short-circuit current the attracting force of fingers/pins to each other somewhat compensates the repulsiv force, caused by the overflowing of current from finger/pin to the knife

through a small number of points of contact of tangency.

Pin contacts widely are encountered in oil switches and disconnectors. Them are utilized as working and arcing contacts. Make contacts fulfill from several pairs of the pin contacts, fastened/strengthened to general/common/total terminal block 6, than is reached the independent contact between fingers/pins and contact knife and an increas the thereby of a total number of points of contact of tangency.

As arcing contacts are applied the nonself-adjusting pin contacts with easily detachable fingers/pins.

In pin contacts proceeds a comparatively weak self-purification of contact surfaces from oxide film. Deficiency/lack is also the presence of contact resistance in the points of connection of flexible members 3 with fingers/pins and terminal block. The oxidation of these connections, especiall intense with the work of contact in air, leads to overheating of contact.

Recently as make contacts they were adopted simpler and more reliable pin contacts without flexible members with spiral contact springs. One of such constructions/designs is shown in Fig. 12-13 (the make contacts of oil breakers of the type MGG - see §17-3).

Contact pins 1 are in pairs arranged/located from both sides of contact current-carrying plate 2. There are no flexible members. In the connected position fingers/pins 1 are pressed against contact knife 3 and against contact plate 2 with the aid of springs 4, put on to the bolts, passed into openings/apertures in fingers/pins 1 and contact plate 2. Flanges 5 on the upper part of fingers/pins 1 fix/record their contact with plates 2.

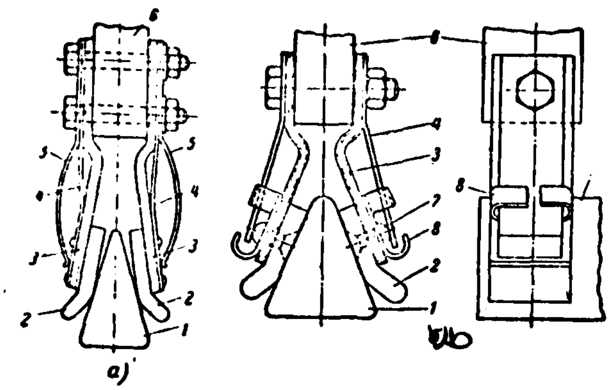

Fig. 12-12. Pin contacts. a) nonself-adjusting; b) adjusting themselves.

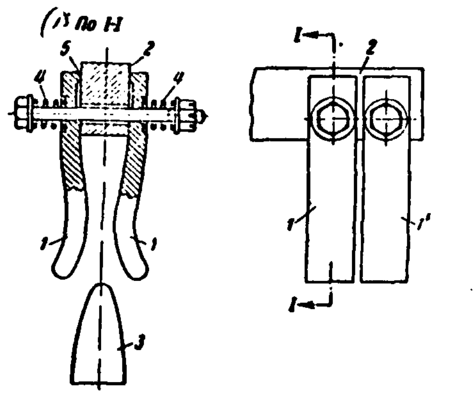

Fig. 12-13. Pin contacts of oil breakers with small space of oil.

Key: (1) On.

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During closing/shorting and interrupting the contacts flanges 5

are rolled on plates 2, as a result of which barely occurs the self-purification of contact surfaces. Somewhat better clean themselves with mutual slip fingers/pins and knife. In the case of the work of contact in air for the purpose of decrease of transient resistance practices silver plating of fingers/pins and contacting with them contact surfaces.

In these contacts motionles element/cell can be the knife or fingers/pins.

Pin contacts can be carried out and with point contact as this is shown in Fig. 12-14. Motionless hemispherical contacts 1 are fastened/strengthened to flexible copper connections/communications 3. Slide contact is carried out in the form of flat/plane knife 5. Pressure in contact create flat/plane steel springs 4. Flexible members 3 and springs 4 are attached by bolts on terminal blcck 2.

During closing/shortin and interrupting knife 5 is moved vertically (along its vertical axis). The slip of contacts 1 along knife provides good self-cleaning of contact.

Is lower than contacts 1 on copper plates 6 attached brass guard ring 7. During interrupting of the contact when knife 5 is moved downward, the arc, arising initially between the ends/leads of knife

and contacts 1, is moved from the latter to guard ring. Thus, contacts 1 are not subjected to the prolonged effect of arc, whic increases their service life.

Similar contacts are applied in switches to small rated currents and small value of the disconnected short-circuit current.

Socket contacts (Fig. 12-15) consist of several contact segments 1, which form together receptacle - the hollow cylinder, cut lengthwise on part. Each segment is equipped with spring 2 and is connected by current-carrying connection/communication 5 with contact holder 6. Springs 2 rest into ring 3, on which there are flanges for the springs (in some constructions/designs receptacle is supplied with the housing, into which rest the springs, as in Fig. 12-16).

Slide contact 4 fulfill in the form of rod or tube by diameter, somewhat greater than the inside diameter of the compressed receptacle. Upon start the rod separates/expands segments, presssing springs, than it is provided the necessary pressure in contact. Each segment independently is pressed against contact bar.

Socket contact are very reliable; therefore them greatly are used extensively in high-voltage switches both as the workers and as arc-suppression ones. With burning the segments can be replaced.

Are fulfilled also socket contacts without flexible members, as shown in Fig. 12-16. entering the receptacle slide contact 3 wrings out contact segments 2, clusters this lower flanges A of segments are pressed against the surface of the neck in contact holder 1. Each segment is contacted with ro and with holder at one point.

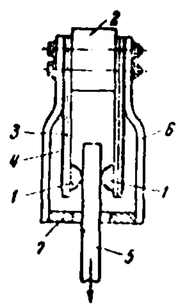

Fig. 12-14.

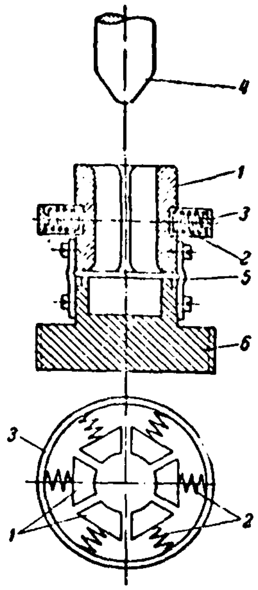

Fig. 12-15.

Fig. 12-14. finger/pin point contacts.

Fig. 12-15. Socket contact with flexible members.

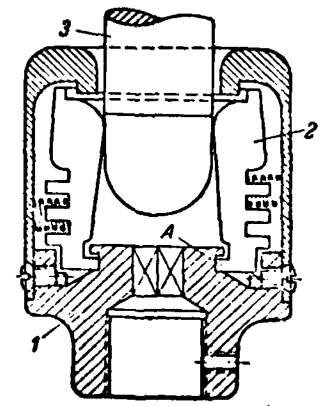

Fig. 12-16. Socket contact without flexible members.

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For decreasing contact resistance is collected/built the receptacle of a sufficiently large number of flat/plane segments.

The upper part of the housing of receptacle performs the role of guard ring - with cutoff/disconnection the arc burns between the end/lead of the ro and the upper part of the housing of receptacle, which prevents the fusing of segments.

End-type contacts can be also flat/plane, linear and point.

Examples of flat/plane end-type contacts they are (Fig. 12-17): plane - the end/face of rod (a), rod - rod (b), plane - the end/face of tube (c), tube - tube (d).

Linear end-type contact is obtained when one of contacts (e) or both have a form of cylinder. Point end-type contacts is obtained with the contact of plan and hemisphere (f) or two hemispheres.

End-type contacts are contacted in a small number of points; therefore in them are observed considerable repulsive forces with the course of short-circuit current. For stabilization is necessary large pressure in contact.

During closing/shorting and interrupting the end-type contacts does not occur their self-purification; at a large pressure in the contact film of oxide it breaks down itself, but it is not driven out, but i is indented into the metal of contact.

Sufficiently considerable contact resistance of end-type contacts makes it possible to apply them in switches to comparatively small rated currents (to 800-1000 A). Great use/application they found in switches by voltage above 1000 V.

End-type contacts are applied as working and arcing contacts. Fusing by the arc of flat/plane end-type contacts sharply increases their contact resistance. Therefore they, as a rule, have easily change caps which in a number of cases manufacture from refractory metals and alloys.

Especially badly break down themselves with arc the ends/faces of tubular contacts. Therefore tubular contacts are applied only in switches with gas or air blast when the flow of gas or air displaces arc from the end/face of tube to its internal surface as that shown in Fig. 12-18.

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The caps of the working in air end-type contacts it is expedient to cover/coat with silver or to manufacture fro a compound of silver with tungsten.

Fig. 12-19 in the form of an example gives the end-type contact of oil breaker. Slide contact 2 is carried out in the form of copper hollow tube with detachable brass cap. Fixed contact 1, which also has detachable cap, with the aid of flexible members 3 is electrically connected with housing 6. Spring 4 creates the necessary pressure in contact.

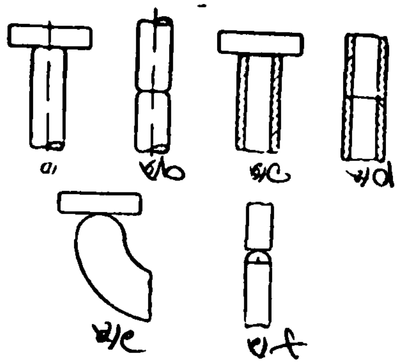

Fig. 12-17. Types of end-type contacts.

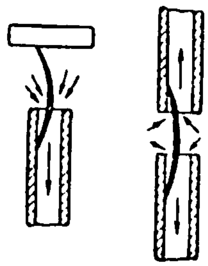

Fig. 12-18. Arc on end-type tubula contacts in air-blast breaker.

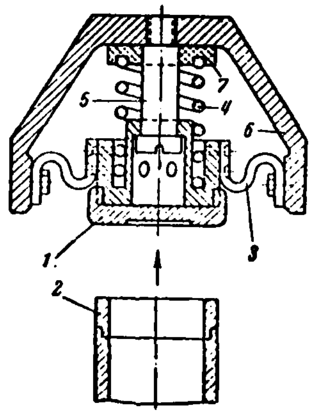

Fig. 12-19. End-type contact.

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Spring 4 is necessary also for preventing the rigid impact with contact of contacts during start. On the deformation of spring is expended/consumed the kinetic energy, stored up in slide contact upon the start (the same it is possible to speak also about the springy elements/cells of other contacts).

Upon start after first contact both contacts for a while continue to move upward, pressain spring. Contact 1 is moved upward on guide rod 5. Plastic cap/hood 7 insulates spring 4 from housing 6.

Brush contacts (Fig. 12-20) are collected/built from elastic thin copper or bronze plates (0.1-0.5 mm). Brush can fulfill the roles of movable 1 and motionless 3 contacts. As the second contact apply massive area contacts 2 or wedge-shaped knives 4. The plane of brush usually forms certain angle with that plane, to which it is superimposed. By this is provided certai deformation of the plates of brush in the connected position and contact of each plate of brush with contact plane (minimum at one point). For an increase in the force of pressure the brushes additionally supply with steel springs 6. In a good state contact resistance brush contacts is small; therefore earlier them were used extensively in switches to large rated currents.

At present brush contacts apply increasingly less frequently especially in switches with a voltag above 1000 V. Is explained this by their comparatively large cost/value, poor mechanical properties and inconstancy of contact resistance.

During closing/shorting and interrupting the brush contacts frequently are observed the residual deformations of the plates of brushes, caused by the impact of brush about area contact, by the tail heaviness of plates with slip on the plane, etc. Is observed also the deformation of the plates of brush with the course of short-circui current when appear the electrodynamic forces, which attempt to finish harvesting plates from contact plane. In the latter case is possible the sparking and fusing of plates. An increase in contact resistance entails overheating the plates of brush, decreasing the elasticity of plates and further deterioration in the contact. Brush contacts require very careful supervision in operation after their state.

Contact resistance of brush contact strongly affects of oxidatio of contact surfaces.

As arcing contacts brush contacts it is not possible to apply. Switches with brush contacts are compulsorily supplied with arcing contacts.

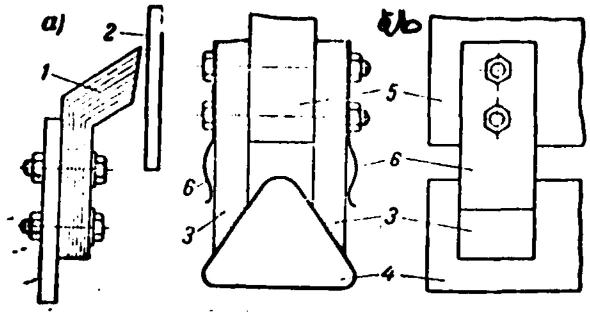

Fig. 12-20. Brush contacts. a) the brush contacts of the air circuit-breakers; b) the brush contacts of oil breakers.

Chapter thirteen.

Brief information about the extinction of electric arc in the disconnecting apparatuses.

13-1. General information about electric arc.

The stud of the disconnecting apparatuses, the correct evaluation/estimate of their special features/peculiarities and their proper operation are impossible without the clear understanding of the occurring in them processes with their cutoff/disconnection. The cutoff/disconnection of circuits for current, and especially the circuits of high voltages, is accompanied, as a rule, by the onset on the contacts of the disconnecting apparatuses of electric arc, which

must be extinguished as rapidly a possible. Taking into account this, is presented below brief information about the fundamental phenomena, which occur in electric arc during its combustion and extinction, in the space, necessary for the understanding of equipment and work of the disconnecting apparatuses.

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In the presence of the disagreement of the contacts of the switch between them is formed the electric field whose intensity/strength greater, the greater the applied to contacts voltage and the les the distance between them. Under the action of this electric field the free electrons, which are located in the gap/interval between the contacts (in any gas there is certain number of free electrons), begin to be moved at a high speed in direction to the anode and on their path they collide with atoms or molecules gas. If at the moment of this electron collision possesses the specific reserve of kinetic energy, then it is capable to dislodge/chase from the particle of gas (molecul or atom) one or even several electrons, as a result of which instead of the neutral particle of gas are formed the free electrons and the positively charged/loaded ion. This phenomenon is called of the impact ionization of gas.

The newly forming free electrons also are moved to the anode

and, after acquiring the sufficient rate, in turn, they participate in the impact ionization of gas. Appears the avalanche of moving to the anode electrons, which rapidly ionize the gap/interva between contacts [L. 5-1 and 6-4].

The necessary for impact ionization reserve of kinetic energy electron accumulates, nursing in path space for elongation/extent of which is a specific potential difference, and having respectively increased by this method its rate under the action of electric field. If electron clashs with the particle of gas earlier than it will acquire the reserve of energy, sufficient for impact ionization, then ionization it will not follow and acquire electron energy will be consumed for the excitation of neutral particle.

The ionization of the particle of gas is possible also as a result of the series/row of its consecutive collisions with the electrons, which possess insufficient for impact ionization by the reserve of kinetic energy. Consecutive collisions increase the degree of excitation of the particle of gas, what also leads to its ionization (ionization due to gradual energy storage - the so-called cumulativ ionization).

With an increase in the applied to contacts voltage, i.e., with an increase in the electric intensity, the impact ionization is

amplified, since electron accumulates the energy, sufficient for impact ionization, for the elongation/extent of smaller.

The initial appearance of free electrons between the diverging contacts of switch is explained also by the following phenomena. It is known that from the surface of hot electrode into surrounding space ar emitted the free electrons (phenomenon of the thermionic emission). With the cutoff/disconnection of switch the pressure in contacts and a number of points of their contact decrease, as a result of which contact resistance and, consequently, also heating of contacts rapidly increase. Therefore with the cutoff/disconnection of high currents at breakaway torque of contacts from each other on cathode usually are strongly incandescent sections, which radiate free electrons. Furthermore in the initial stage of the disagreement of the contacts when the distance between them is still very small, electric intensity is usually very large and sufficient for the extraction of free electrons from the surface of cathode (autoelectronic emission), to what it contributes the elevated temperature of cathode.

The free electrons, which are formed as a result of thermoelectronic and autoelectronic emissions, under the action of electric field are moved to the anode participating in the impact ionization of gas of the gap/interval between contacts, as this was

discussed above.

As a result of ionization in the gap/interval between contacts appear the positively and negatively charged/loaded particles of gas, i.e., space between contacts proves to be the filled so-called gas-discharge plasma, which possesses large electrical conductivity. Under the action of the applied to contacts voltage occurs electrical breakdown across gap betwee them and striking of the arc; in circuit appears the electric current. Let us recall that the voltage, with which occurs by the test/sample of the gap/interval between contacts and the striking of the arc, is called breakdown (initial) voltage, and the corresponding value of electric intensity - by a breakdown (initial) intensity/strength. The value of breakdown strength characterizes dielectric strength of dielectric.

Electric arc is the form of the independent discharg through the gas which is characterized by a small cathode drop, usually not exceeding 10-20 V (for greater detail, see below), by large current densities, which reaches by 10,000 A/cm^2 and more, and by the high temperature of gas-discharge plasma.

The temperature of gas of the center section of the arc (crux of the arc), on which is moved the large part of the electron stream, reaches very high values - to 10,000°C is above, depending on the

current strength, propertie of the ambient gas medium and its pressure. The temperature of gas on the surface of arc composes 3000-4000°C and more.

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The high temperature of arc is supported due to thermal energy, isolated in it by current, i.e., due to electric power, applied to it from electric system.

For the existence of the arc between contacts it is necessary that the circuital current would be not less than 80 mA, and the voltage between contacts is not less than 10-20 V.

As a result of the very high temperature in the center section of the gas-discharge plasma its conductivity in essence is supported because of the intense thermal ionization of gas which occurs as follows. Those falling into the high-temperature range of the particle of gas come in very rapid motion. If temperature is high and the moving/driving particles possess sufficient kinetic energy, then during mutual collision occurs their decay and the formation of free electrons and positiv ions.

The thermal ionization of gases begins at temperature of

9000-10,000°C, and vapors of metal at temperature of approximately 4000°C. Since in arc in switches always there is certain quantity of incandescent vapors of metal, and temperature of rod of arc of higher than 4000-5000°C, then the intensity of thermal ionization proves to be sufficient for maintenance conductivity of arc gap.

The intensity of thermal ionization depends on the properties of gas and first of all, from its dielectric strength and temperature of thermal ionization, and from pressure. With pressure rise the thermal ionization of gas is impeded, since with an increase of the number of particles of the gas in given space increases the probability of the premature collisions of the particles when they during collision yet do not possess the kinetic energy, sufficient for their ionization.

With an increase of the arcs current its temperature and thermal spee of the particles of the gas grow/rise, in consequence of which the thermal ionization of gas is amplified (at larger rate the particle motions of gas acquire the necessary for thermal ionization reserve of kinetic energy with the path/range of smaller path).

From the given in Fig. 13-1 volt-ampere characteristic of arc, i.e., the dependence of voltage from current in it $U_д=f(I_д)$, with an increase in the current voltage, i.e., the voltage, necessary for its maintenance, decreases It is explained this by the fact that the

electrical arc resistance changes in quadratic dependence on arcs current.

On measure of deviation of the contacts of switch the distance between them rapidly grows/rises, and electric intensity in arc stream respectively decreases. As a result of this the intensity of impact ionization also rapidly decreases and therefore it already little affects the conductivity of arc gap.

In electrical arc continuously occur two opposit processes: the process of ionization, i.e., the formation/education of the new charged/loaded particles, and the process of deionization, i.e., neutralization or disappearance of the charged/loaded particles.

The deionization of arc gap occurs by recombination and diffusion of ions.

The phenomenon of recombination or recombination of the charged/loaded particles lies in the fact that the positively and negatively charged/loaded particles come into contact an they give up to each other excess charges, as a result of which are formed neutral particles.

In arc column is observed predominantly the recombination of

positive and negative ions. The direct recombination of electrons with positive ions is scarcely probable, since the rate of electron motion is approximately/exemplarily 1000 times more than the rate of the motion of ions.

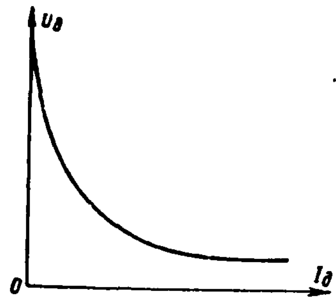

Fig. 13-1. The volt-ampere characteristic of electric arc.

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It is assumed tha the electron, as more movable particle, first charges the neutral particle (as "adheres" and by it during collision), as a result of which is formed negative ion. Then the negatively and positively charged/loaded ions, which have approximately/exemplarily equal masses and rates of motion, mutually are attracted/tightened and, touching, are converted into neutral particles.

The intensity of recombination depends on electric intensity: the less the electric intensity, the les the rate of the motion of ions and the greater the probability of their recombination. Hence it follows that in alternating current arc the recombination is especially intense at those moments/torques when voltage is close to zero.

The intensity of recombination depends also on temperature and section of the arc: the lower temperature and less the section of arc, the more intense the recombination.

The intense recombination of the charged/loaded particles is observe also on the surface of the solid dielectric with which is contacted the electric arc (for example, the wall of tube or slot in which it burns arc). Recombination on the surface of solid dielectric occurs so that first the electrons, as more movable particles, charge surface to certain negative potential, with which negative ions and electrons are repulsed from this surface, but positive ions are attracted/tightened, and, falling to surface, they lose their charge.

The diffusio of ions from arc into the environment occurs as a result of the thermal displacement/movement of particles, caused by a considerable difference in the temperatures of arc and environment, and large difference in ion concentration in arc and in the environment. The diffusing into the environment ions lose their charge by recombination with electrons or negative ions, which are located in gaseous medium. Thus, diffusion also leads to the decrease of a number of positively charged/loaded ion in arc in consequence of which its conductivity decreases.

If the environment is located in relative rest, then the diffusing from arc ions are accumulated/stored around arc and they create positive the space charge, which impedes the further diffusion of the ions, which have the charge of the same sign. The intensity of diffusion in this case depends on the recombination velocity of ions in the environment.

Diffusion is amplified with blowing of arc by any relativel cold and neutral gas, since in this case increases a difference in the temperatures in arc and in surrounding medium and is amplified the recombination of the diffusing ions, since with the flow of gas to arc enter all new and new free electrons. The same result gives the displacement/movement of arc in the environment.

The diffusion of ions depends both on the difference in the temperatures of the arc and the environment and from the ratio of the perimeter of arc to it section. The greater the relationship/ratio indicated, the more a number of ions diffuses into the environment. With an increase in the arc length the diffusion also increases.

The deionization of ions occurs also near electrodes.

The positive ions formed in the arc are shifted to the cathode. Near the cathode, at a negligible distance from it (on the order of 10^{-4} cm) the concentration of positive ions proves to be the greatest, and there occurs a certain accumulation of the positive ions and the formation of the so-called positive space charge. The latter creates near the surface of the cathode an electrical field of very great intensity sufficient for equalizing the electrons from the surface of the cathode (field emission). This field imparts to ions which shift toward the cathode so significant a reserve of kinetic energy that upon impact against the surface of the cathode, from it free electrons will be dislodged. Electrons exiting from the cathode surface are partically consumed for recombination with the positive ions and are partially shifted in the direction toward the anode. The neutral particles formed from recombination of the ions and electrons continue by inertia to move toward the cathode and have impact against its surface with force.

As a result of the bombarding by the particles of gas, the surface of the cathode is heated up, and the fusion and atomization of the metal of the contact occur. The most heated part of the cathode possessing a temperature of the order of 1500° C and higher is called the catode spot. At such a high heating temperature of the metal, there occurs a thermionic emmission from the cathode surface (predominantly from the surface of the cathode spot). The electrons being emitted are also partly recombined with the positive ions which approach the cathode and are partly carried away by the electrical field in the direction toward the anode.

Thus, in the space, which adjoins directly cathode (l_k in Fig. 13-2), occurs continuous disappearance of positive ions, in consequence of which electrical conductivity per the unit of length in this part of the arc is considerably less tha in arc stream (zone of a cathode drop).

Forming in arc negative ions partially recombine, as noted above, with positive ions, and partially they are moved to the anode. At small distance from the anode from these adequate/approaching it negative ions blow away the electrons and they depart to the anode. The forming neutral particles on inertia continue to move to the anode and bombard it. Thus, in the space, which adjoins anode (l_a in Fig. 13-2), ionic density is also smal (zone of an anode drop).

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Voltage distribution along arc is shown in Fig. 13-2. Near electrodes are observed abrupt changes in the voltage: in near-cathode space l_k - a cathode drop U_k, in near-anode space l_a - an anode drop U_a, caused by those deionization processes near the electrodes, which were discussed above.

The value of a cathode drop depends on the material of electrodes and medium, in which burns the arc, and usually do not

exceed 10-20 V. An anode drop is very variably and to large degree depends on arcs current. Usually $U_а < U_к$ and with high currents is close to zero.

Along arc stream $l_{ст}$ the voltage changes considerably slower and the overall voltage drop across it comprises $U_{ст}$. In arc stream a number of positive and negative charges per the unit of length is approximately/exemplarily equal; therefore electric intensity along arc stream, i.e., voltage on the unit of its length, it remains constant.

With high currents the voltage, necessary for arc maint-nance, must be not less $U_д \approx U_к + U_{ст}$. Hence it is clear that the arc between electrodes can exist only in such a case, when the applied to them voltage in any case is more than a cathode drop.

In short low-voltage arc a cathode drop has vital importance, since it is commensurated with a voltage drop across arc stream. In long high-voltage arc a cathode drop has negligible value in comparison with a voltage drop across arc stream.

Essential effect on the process of the deionization of arc has also the gaseous dissociation in high-temperature range of arc. The molecules of gas, falling into the high-temperature range of arc,

come into very rapid irregular thermal agitation, and if temperature of gas, but thereby the rate of the motion of molecules is sufficiently great, then during mutual molecular collision occurs their decay to atoms. This decay of molecules to atoms is connected, as is known, wit large heat expenditure. Forming atoms diffuse from arc into the environment, they are connected there into molecules and free/release thermal energy, expended for their dissociation. Thus, is amplified heat transfer into the environment and cooling of arc, which entails the decrease of thermal ionization and the amplification of the recombination of the charged/loaded particles.

The difference between dissociation and thermal ionization consists in the fact that for therma ionization is necessary the temperature not less than 4000-5000°C (in the presence of vapors of metal in arc), while the dissociation of molecules to atoms occurs also at lower temperatures.

From that presented above I can draw the conclusion that the electric arc is phenomenon not only electrical, but also thermal. Thermal processes in arc and heat exchange between the arc and the environment play very large role and affect the occurring in it electrical processes [L. 9-1]

13-2. Fundamental methods of the extinction of electric arc.

The extinction of electric arc is reached by effect on the occurring in it ionizing and deionization processes. The first must be sharply weakened, and the second - are intensified. Of that presented it previously follows that for this, first of all, necessary to weaken/attenuate or to entirely discontinue thermal ionization and to enforce the recombination of the charged/loaded particles and diffusion of ion into the environment.

The decrease of thermal ionization and the amplification of recombination can be achieved/reached by cooling the arc. The effective amplification of recombination is achieved at intimate contact of arc with the surface of dielectric.

Diffusion is amplified with the blowing of arc by any gas or with the rapid adjustment of arc in the environment.

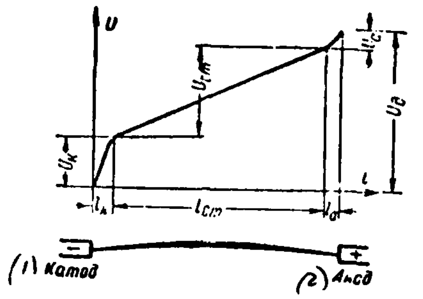

Fig. 13-2. Voltage distribution along arc.

Key: (1). Cathode. (2). Anode.

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The intensity of the deionization of arc to large degree depends on the properties of that medium, in which burns the arc: the greater the thermal conductivity, dielectric strength, temperature of thermal ionization and heat capacity of gaseous medium, the more intense the process of deionization, the easier it is to clear the circuit. The best arc-arresting properties possesses hydrogen and by somewhat worse water vapor, carbon dioxide and air.

Fig. 13-3 gives arc characteristics in hydrogen and in air (at an identical pressure), from which it is evident that, other conditions being equal, for arc maintenance in hydrogen is necessary the considerably larger electric intensity; therefore to clear the circuit in hydrogen it is easier than in air.

Arc extinction in hydrogen takes the place in oil breakers, where under the action of the high temperature of arc certain quantity of transformer oil, which fills a tank of switch, evaporates and is decomposed/expanded into the composite/compound component parts, the main thing from which is hydrogen. This hydrogen,

generated by oil under the action of the high temperature of arc, and is utilized for its extinction.

In some disconnecting apparatuses are applied solid organic materials (fiber, organic glass, polyvinyl chloride plastic, etc.), which under the action of the high temperature of arc generate hydrogen, carbon dioxide and water vapor, utilized for an arc extinction.

Arc extinction in air is used extensively in the disconnecting apparatuses of low and high voltage.

Substantially affects the process of the deionization of arc the pressure of the gaseous medium, in which burns the arc. The higher the gas pressure, the greater a number of particles of the gas per unit of volume, the less the distance between them; therefore with an increase in the gas pressure thermal ionization is impeded, and cooling arc is amplified. For arc maintenance is required larger voltage, that illustrates the curve of Fig. 13-4.

For the deionization of arc the definite effect exerts also the material of contacts. Is most expedient the use/application of metals of high-melting ones, with the high temperature of steam generation and with large thermal conductivity and heat capacity (decrease of a

thermionic emission and quantity of vapors of metal in arc).

With an increase in the rate of the disagreement of the contacts of switch more rapidly increases the arc length and its surface, thanks to which is amplified cooling arc and diffusion of ions into the environment and, consequently, also deionization of arc.

In the disconnecting apparatuses are applied the different methods of accelerating the extinction of the electric arc, based on the examined above phenomena and processes in arc. Great use/application in the arc-suppression devices/equipment of the disconnecting apparatuses found the following methods of arc extinguishing:

1. Arc extinction with the aid of the gas blast, directed along or across arc (Fig. 13-5). Arc in turbulent, i.e., eddy-like, flow of gas intensely is cooled and is deionized, and the more intense, the higher the gas velocity. To the deionization of arc to large degree contributes the fact that the eddy-like moving/driving particles of gas penetrate the arc stream.

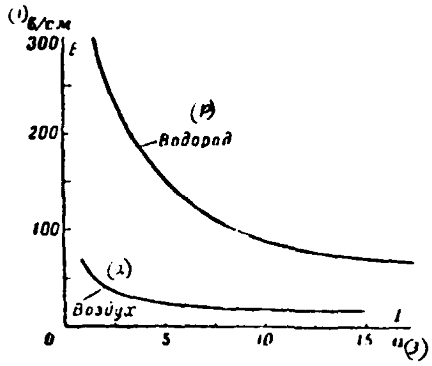

Fig. 13-3. Dependence on the current of the strength of the field of arc stream B [V/cm], which burns in air and in hydrogen.

Key: (1). V/cm. (1A). Hydrogen. (2). Air. (3). A.

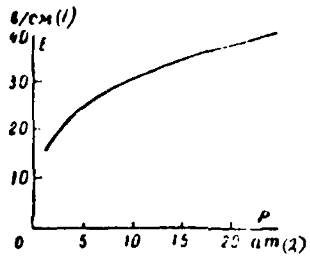

Fig. 13-4. Dependence of strength of field of arc stream on air pressure (Voizik's data).

Key: (1). V/cm. (2). atm(tech).

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The best results gives blast by the relatively cold and neutral gases.

Longitudinal gas blast (Fig. 13-5a) is used extensively in the switches of all voltages. Transverse blast is most effective with fulfillment on the outline of Fig. 13-5c, when across arc are established/installed partitions from insulation, blocking free displacement arcs in the direction of the flow of gas (as in Fig. 13-5b). In the presence of insulating partitions is provided the more intimate contact of gas flow with arc, is facilitated the penetration of the particles of the gas inside arc stream, are reached large length and surface of arc. All this provides the energetic deionization of arc.

In oil breakers and switches with solid gas-generating organic materials for a blast are utilized the gases (see above), generated by oil or materials indicated under the action of the high temperature of arc. In these switches the blast is realized with the aid of the explosion chambers of different constructions/designs.

In high-voltage air-blast breakers the air enters from special delivery air chamber which is supplemented from blowing plant. Blast appears simultaneously since the beginning of the disagreement of contacts.

2. Arc extinction by its displacement/movement in environment finds use mainly in disconnecting apparatuses of low voltage. The

displacement/movement of arc in the environment has the same effect as gas blow-out, since during arc displacement a sort of counter gas blow-out arises.

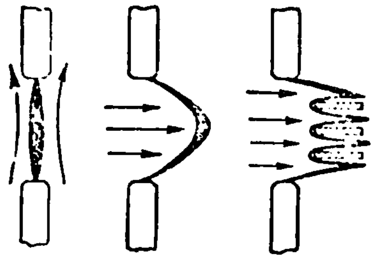
Displacement of the arc in the ambient medium is possible: a) under the action of the electrodynamic forces of current interaction in different parts of the arc, and also arcs current with current in the current-carrying parts of the apparatus (Fig. 13-6, to the displacement/movement of arc it upward contributes also the flow of warm air); b) during interaction of arcs current with any mass from magnetic material (Fig. 13-7) and c) with the aid of the magnetic blow-out (Fig. 13-8).

Interaction between the arcs current and the mass from magnetic material (steel tank, steel plate, etc.) appears as a result of the displacement of the magnetic flux of arc under the effect of magnetic mass. Arc attempts to occupy such position in which the reluctance for a flow will be minimum.

The principle of the magnetic blow-out is clarified in Fig. 13-8, where for simplicity is assumed the displacement/movement of arc over horns 1. Blowout coil 2 is arranged/located so that its magnetic flux would be directed perpendicular to arc and was created the effort/force, moving arc upward (according to the rule of left hand).

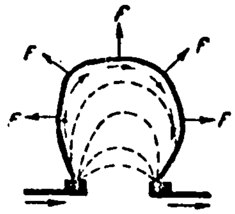
The curves of Fig. 13-9 show an increase of the strength of the field of arc stream in dependence on the rate of its motion in magnetic field.

3. Arc extinction in narrow slots or channels of small diameter from solid insulation. It was previously indicated that the intimate contact of arc with dielectric leads to its very intense deionization as a result of the energetic recombination of the charged/loaded particles on the surface of dielectric, of pressure increase in slot or in channel and cooling arc with dielectric. The given in Fig. 13-10 curves show, how considerably changes the strength of the field of arc stream, which burns in narrow slot and in the channel of a small diameter.

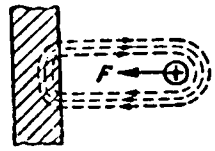


a) b) c)

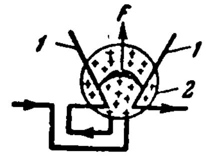
13-5



13-6



13-7



13-8

Fig. 13-5. Gas blast: a) longitudinal; b) transverse; c) transverse in the presence of transverse insulating partitions.

Fig. 13-6. Extension of arc under the effect of electrodynamic forces.

Fig. 13-7. Displacement/movement of arc under the effect of mass from magnetic material.

Fig. 13-8. Displacement/movement of arc under the effect of magnetic blow-out.

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In some arc-suppression devices/equipment the walls of slot or channel fulfill from solid gas-generating materials, for example from organic glass, fiber, etc. In these devices/equipment under the

action of the high temperature of arc the material of the walls of slot or channel gasses, which leads to an even larger increase in the pressure and to the more energetic deionization of arc.

Arc extinction in narrow slots and channels is utilized in the disconnecting apparatuses by a voltage to 10 kV and rarely to 35 kV. In the form of an example Fig. 13-11 gives the schematic of the arc-suppression grating of the switch of low voltage, which is made from the series/row of the non-arcing insulating plates, situated across arc. For rapid adjustment the arcs into grating apply the blowout coils, arranged/located analogously with that indicated in Fig. 13-8.

The use/application of similar arc-suppression gratings limits the development of arc upward how is reached arc extinction in small space. If switch disconnects the current, which does not exceed the greatest permissible for it value, then arc does not exceed the limits of grating.

At present are used extensively safety fuses with the filling of receptacles with quartz sand. In these safety devices/fuses with burn-out by smelting insert the arc burns in the narrow channel, formed by body by smelting insert, and therefore it is very tightly contacted with the grains of quartz, as a result of which it rapidly

is deionized and goes out.

In apparatuses by the voltage of above 35 kV arc extinction in slots and channels usually do not apply as a result of serious difficulties in the guarantee of the necessary insulation of disruption, i.e., the insulations between the contacts of apparatus after arc extinction.

4. Arc extinction by its separation into several short arcs, which burn between series/row of consecutive metallic plates (Fig. 13-12a). The arc, which appears between motionless 1 and movable ones 2 by contacts, is forced into grating from several metal plates 3, situated perpendicularly to arc. Instead of one long arc appear several consecutively/serially burning short arcs. A voltage drop across short arc, as noted above, in essence is determined by cathode and anode drops. Therefore if we fit such a number of plates so that the applied to the contacts of switch voltage would prove to be less than the sum of cathode and anode drops on all short arcs, then the applied voltage will not be able to support all these short arcs and they rapidly will go out (is in form a cutoff/disconnection of direct-current circuit; the special features/peculiarities of the use of an arc-suppression grating with metallic plates with the cutoff/disconnection of alternating current circuit will be shown into §13-4).

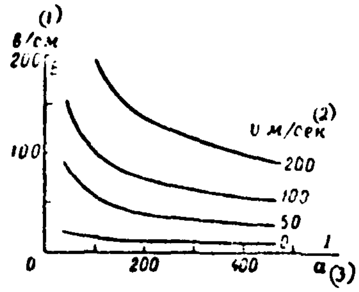

Fig. 13.9. Dependence of the strength of the field of arc stream on the rate of the motion of arc in magnetic field (Kukekov's data).

Key: (1). V/cm. (2). m/s.

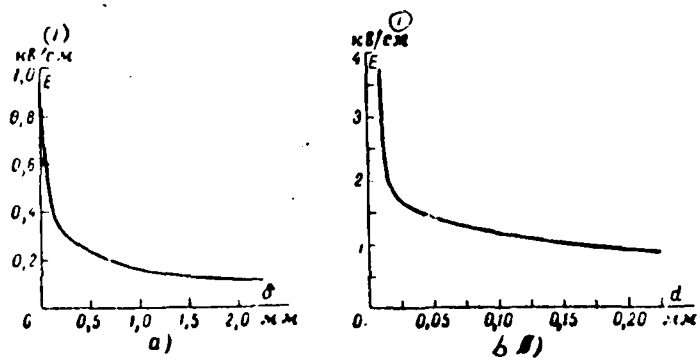

Fig. 13-10. Dependences of strength of field of arc stream on width (Suits' data) and from diameter of channel (b - Slepian's data). δ - width of the slot; d - diameter of channel.

Key: (1). kV/cm.

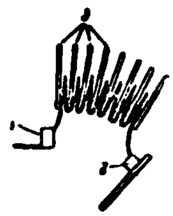

Fig. 13-11. Arc-suppression grating with plates from non-arcing insulation. 1 - fixed contact; 2 - the slide contact; 3 - plate of grating.

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To arc extinction contributes also cooling by their metallic plates of grating.

If the plates of grating are made from copper, then for the purpose the accelerations of the entry of arc into grating apply the magnetic blow-out. With steel plates with rectangular grooves (Fig. 13-12b) the arc is involved/tightened into grating under the action of the force, caused by the displacement of its magnetic flux (as in Fig. 13-7). In the presence of the disagreement of the contacts of switch the arc is formed in the beginning of the rectangular groove of plate (position A in Fig. 13-12b). Rising upward, arc attempts to occupy position B, in which the reluctance for its flow will be minimum. In this position the arc proves to be cut to the series/row

of short arcs. Blowout coils prove to be excessive.

5. Arc extinction with use of multiple break. Switches can be fulfilled with one, two and by a large number of places of disruption in phase as this is schematically shown for one phase in Fig. 13-13. With n-fold disruption it is formed by n of the consecutive arcs in phase whose overall length in n times is more than arc length in switch with one disruption on phases (at the identical rate of the motion of slide contacts). Moreover, the arcs of disruptions undergo artificial deionization; therefore it is obvious that, other conditions being equal, in switches with multiple break is provided the more energetic arc extinction and the possibility of the cutoff/disconnection of high currents with very high voltages.

Switches with multiple break can be constructed to any high voltages and to the very large power of the cutoff/disconnection (see Chapter 17).

In switches with three-four and large gap count in phase must be provided the even distribution of voltage according to various disruptions or groups of disruptions. Is achieved this by start in parallel to the disruptions of high active backs-out resistor.

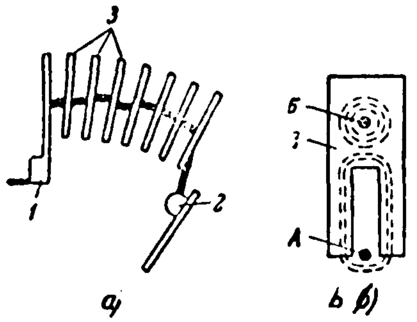

Fig. 13-12. Arc-suppression grating with metal plates (a) and steel plate with rectangular cutout (b).

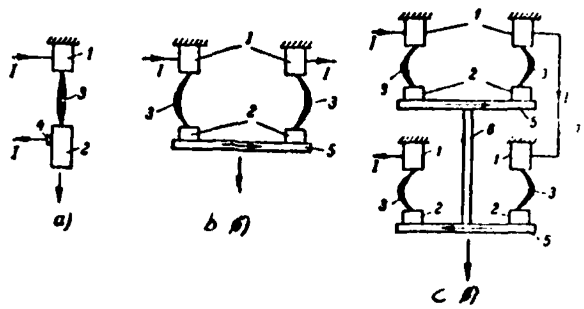

Fig. 13-13. Diagrams of contacts with different number of places of disruption in phase. a) one disruption in the phase; b) two disruptions; c) four disruptions. 1 - fixed contact; 2 - the slide contact; 3 - arc; 4 - slipping contact; 5 - contact crosshead; 6 - insulating rod; 7 - current-carrying connection/communication.

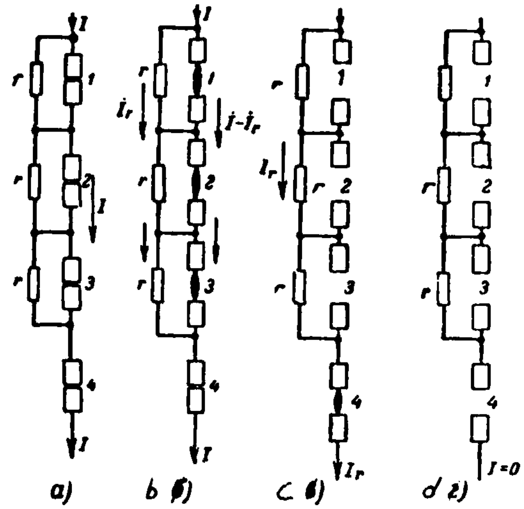

Fig. 13-14. Diagrams of contacts with triple disruption and backs-out resistor. a) is connected; b and c) in the process of the cutoff/disconnection; d) is disconnected.

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Fig. 13-14 gives the diagram of the contacts of one phase of the switch with three disruptions 1, 2 and 3, in parallel by which are connected identical backs-out resistor r. In this case the switch is supplied with the supplementary pair of contacts 4, which are intended for the cutoff/disconnection of current, which takes place through

In the connected position of the switch through backs-out

resistor the current does not flow/occur/last (Fig. 13-14a). With the cutoff/disconnection of switch first diverge fundamental contacts 1, 2 and 3, between which appear three arcs, shunted by resisting of r. supplementary contacts 4 remain locked (Fig. 13-14b).

After arc extinction in disruptions 1, 2 and 3 diverge contacts 4, which disrupt comparatively small current I_n flowing through backs-out resistor (accompanying current). This current is small and the arc between contacts 4 easily goes out (Fig. 13-14, c and d).

Let us note that in some switches of alternating current of very high voltages for voltage compensation on disruptions sometimes are applied the shunt capacitances.

13-3. Cutoff/disconnection of direct-current circuits.

In stable burning direct current arc a number of ionized particles remains constant/invariable; constant in value remains arcs current. In order to clear the circuit of direct current, should be created such conditions under which a number of deionized ions in arc always exceeded a number of newly forming in it ions or, if we proceed from thermal processes in arc so that a quantity of abstracted/removed from arc heat would exceed a quantity of heat, separating in arc within the same time. As a result of this

continuous decrease of a number of ionized particles the arc resistance grows/rises, circuital current decreases and arc goes out.

Since electrical circuits possess certain inductance, the reduction in current in circuit with its cutoff/disconnection unavoidably causes induction in all conductors of circuit of emf of self-induction, which is superimposed on the fundamental voltage of circuit, as a result of which appears the so-called switching surge (Fig. 13-15).

Tahe value of the emf indicated depends on the inductance of circuit and rate of change in the current and is determined from the

$$E = -L\frac{di}{dt}.$$

Rate of change in current (di/dt) depends on the arc-arresting properties of that medium, in which burns the arc, and from the type of the used in switch arc-arresting devices/equipment. The more intense the deionization of arc, the greater rate of change in the current, and the thereby also overvoltage.

For the cutoff/disconnection of direct-current circuits are applied the switches with arc extinction in the air: knife switches, safety fuses, air breakers with insulation or with metal plates. The arc-suppression devices/equipment of these switches provide such rate

of change in the current, at which the overvoltages, which appear with the cutoff/disconnection of direct-current circuit, do not exceed the fourfold value of the nominal voltage of installation, that it does not constitute a threat to the insulation of electrical equipment of the settings up of direct current.

Oil breakers in the installations of direct current they do not apply, since with disruption by them direct-current circuits in the latter appear the overvoltages, dangerous for the insulation of electrical equipment.

13-4. Cutoff/disconnection of alternating current circuits.

The extinction of electrical alternating current arc is facilitated by the fact that through each of half-period the circuital current passes through the zero value and to arc for certain although very short, time interval goes out. In the majority of the cutoff apparatuses of alternating current is utilized this moment/torque of transiting the current through zero - the moment/torque of short-term arc extinction.

Arc-suppression device/equipment should create such condition, so that the arc, after going out at current zero, no longer could be ignited again. In some disconnecting apparatuses the conditions for

final arc extinction are created only after the extension of arc to the comparatively large length; in them the arc exists during 10-15 half-periods and even it is more.

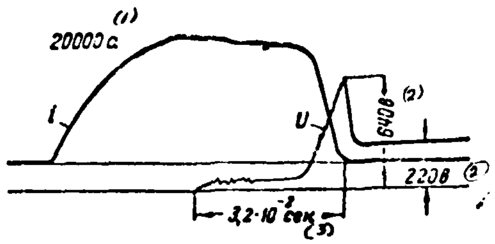

Fig. 13-15. Oscillogram of the cutoff/disconnection of direct current by air circuit breaker (with horns).

Key: (1). A. (2). V. (3). s.

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In the newest disconnecting apparatuses are applied such powerful/thick and ideal arc-suppression devices/equipment, that the conditions for final arc extinction are created in all through several half-periods after the onset of arc.

A change of alternating circuital current from zero to amplitude value is accompanied by an increase in the temperature of arc and by the amplification of thermal ionization - the conductivity of arc gap grows/rises, voltage on arc decreases (see curve u_a in Fig. 13-16). With reduction in current from amplitude value to zero power supplies from network to arc decreases, as a result of which decrease

temperature the arcs and its section and, consequently, also intensity of thermal ionization. Simultaneously is amplified the deionization of arc. voltage increases (Fig. 13-16).

At the moment of transiting the current through zero arcs it goes out, power supply from the network is cut off and temperature of arc gap rapidly descends so, that its thermal ionization ceases. However, certain conductivity of arc gap is retained, since it remains still ionized. Further change in the conductivity of gap/interval depends on the intensity of its deionization.

After arc extinction upon transfer of the current through zero most rapidly is deionized the near-cathode space (in this space, as noted earlier, occurs the intense recombination of positive ions with the electrons, which emerge from the (fraction/portion of microsecond) near-cathode space acquires dielectric strength, equal to 150-250V depending on the temperature of cathode. After arc extinction the ionization in near-cathode space is supported by the electrons, emitted with the incandescent surface of cathode; therefore the lower the temperature of cathode, the less it is emitted electrons from its surface, the less the impact ionization in near-cathode space, the higher dielectric strength of the latter (dielectric strength of gap/interval is determined by that voltage, which is necessary for its breakdown). The remaining part of arc gap

(arc stream) is deionized considerably slower.

The character of a change in dielectric strength of the gap/interval between contacts after arc extinction at current zero show curved $Oa_1 1$, $Oa_2 2$, $Oa_3 3$, $O'a'_1 1'$, etc. in Fig. 13.16.

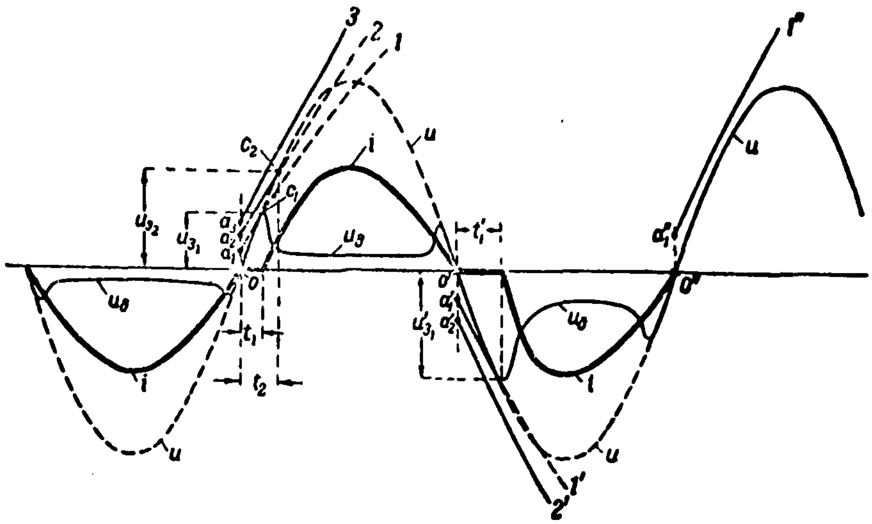

Fig. 13-16. Oscillogram of the cutoff/disconnection of alternating current circuit with resistive load (cos ϕ=1).

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Ordinates Oa_1, Oa_2, etc. of these curves are equal to instantly restored dielectric strength of near-cathode space whose value depends on the type of arc-suppression device/equipment, medium, in which burns the arc, the distances between the contacts also of the series/row of other factors. Curves on sections $a_1 1$, $a_2 2$, etc. show, as changes dielectric strength of the remaining part of arc gap. The character of these curves and their inclination/slope toward the axis

of abscissas depend on the type of the arc-suppression device/equipment, used in this switch. The more ideal the arc-suppression device/equipment, i.e., the more energetic the deionization of the gap/interval between contacts, the more rapid increases its dielectric strength (for example, the curve $a_2 2$ in comparison with the curve $a_1 1$).

Thus, for the time of arc extinction occurs the more or less rapid deionization of arc gap and the decrease of its electrical conductivity. New striking of the arc into the following half-period is possible only in such a case, when the voltage, applied between the contacts of switch, proves to be sufficient for the breakdown of arc gap and in any case not less 150-250V.

The voltage, with which it occurs striking of the arc, call breakdown or ignition voltage arcs.

By phenomenon indicated above of instantaneous restoration of dielectric strength of near-cathode space is explained simplicity of the cutoff/disconnection of alternating current circuits by voltage of up to 220V by switch. With the cutoff/disconnection of these circuits the appearing on the contacts of switch electric arc usually burns only to the first transition/junction of the current through zero, i.e., for a period of time is not more than 0.01 s. With the

voltage of alternating current 380 and 500V is possible the onset of prolonged arc, especially with the cutoff/disconnection of powerful/thick circuits. In the latter case at the moment of breaking of contacts on the surface of cathode can be formed the strongly incandescent flanges from surface of which are emitted the electrons, which ionize near-cathode space, and consequently, that decrease its dielectric strength, which is restored at the moment of transiting the current through zero.

A phenomenon of near-cathode deionization at current zero can be utilized, also, for the arc extinction of any voltage. For this the appearing between the contacts of switch arc they force into the arc-suppression grating, which consists of the series/row of the copper or steel plates, situated perpendicular to the arc (see §3-2; Fig. 13-12). Arc overlaps the gaps/intervals between plates and thus it is granulated by several consecutive short arcs, which burn between these plates. Is also created corresponding number of cathodes. Upon transfer of the current through zero, all these arcs go out simultaneously and almost instantly in each cathode (plate of grating) is formed the deionized space with dielectric strength of order 150-250V. If total dielectric strength of all near-cathode spaces will be more than voltage on the contacts of switch, then arc no longer will be restored/reduced and the process of cutoff/disconnection will be completed.

With the extinction of the long alternating current arcs of high voltage the primary meaning has the deionization of arc stream. In this case the lifetime of the arc between the contacts of switch depends on the strength of disrupted current, cosϕ, the voltage and the parameters of network (L and C), and also from the type of the arc-arresting device/equipment.

First of all let us become acquainted with the special alternating current circuit with purely resistive load (cosϕ=1). Fig. 13-16 gives the exemplary/approximate oscillogram of arc extinction, for the case indicated, on which they are designated: u - a line voltage (on the terminals/grippers of source); i - current, flowing through the arc; u_A - voltage (voltage drop across arc). In the examination of oscillogram one should remember that the contacts of switch for the time of arc extinction diverge from certain rate.

Since arc resistance active, the voltage u_A and current change direction simultaneously. The curve of voltage has saddle-shaped form, since with an increase in the current, flowing through the arc, its resisting decreases, and consequently, decreases the voltage, necessary for its maintenance.

At the moment of 0 arc extinction at current zero dielectric strength of the gap/interval between contacts instantly reaches value of Oa_1 and then it changes on the curve $a_1 1$, as about this it changes on the curve $a_1 1$, as this was discussed above. Simultaneously on sinusoid grows/rises voltage u, applied to the gap/interval between contacts. Since in the beginning of process dielectric strength of gap/interval exceeds the applied to it voltage, then arc cannot again inflame immediately after the transition/junction of the current through zero.

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At that moment/torque when the applied to gap/interval voltage proves to be equal to its dielectric strength (intersection of curves at point c_1), gap/interval breaks down again it ignites arc. Voltage $u_{з1}$ is the ignition voltage of arc. Thus, for a period of time t_1 arc does not burn.

After arc extinction at moment/torque O' it does not burn already for a period of time $t'_1 > t_1$, which is explained by the larger value of the electric strength of gap/interval (curve $O'a'_1 1'$) with the new, larger distance between contacts. Corresponding to this increased and the ignition voltage of arc $u'_{з1} > u_{з1}$. After arc extinction at moment/torque O" the arc no longer is restored, since

dielectric strength of gap/interval (curved 0" a "$_1$1") remains always more than voltage on arc gap. The process of cutoff/disconnection is completed.

If switch is supplied with the more advanced arc-suppression device/equipment, then dielectric strength of gap/interval will change on the curves $0a_22$ and $0'a'_22'$. In this case after arc extinction at moment/torque 0 arc are restored in time t_2, also, with considerably larger ignition voltage u_{32}. After extinction at moment/torque 9' arc no longer are restored, since dielectric strength of gap/interval (curve $0'a'_22'$) always remains more than the voltage, which is restored on the contacts of switch.

By the use/application of the arc-arresting device/equipment with even more energetic deionization (curve $0a_33$) it is possible tc achieve final arc extinction at moment/torque 0. deionization of arc gap by the use/application of special arc-suppression devices/equipment, it is possible to considerably shorten the lifetime of arc in switch.

Let us note that the pauses of current t_1, t_2, t_1' Fig. 13-16 shows exaggerated, since in actuality their duration is measured by microseconds.

Fig. 13-17 gives the oscillogram of the cutoff/disconnection of alternating current circuit in inductive current, which corresponds to the cutoff/disconnection of circuit during short circuit. Designations are left the same as in Fig. 13-16.

The basic difference in the case in question from preceding/previous consists in another character of resumption of voltage on the contacts of switch after the transition/junction of the current through zero.

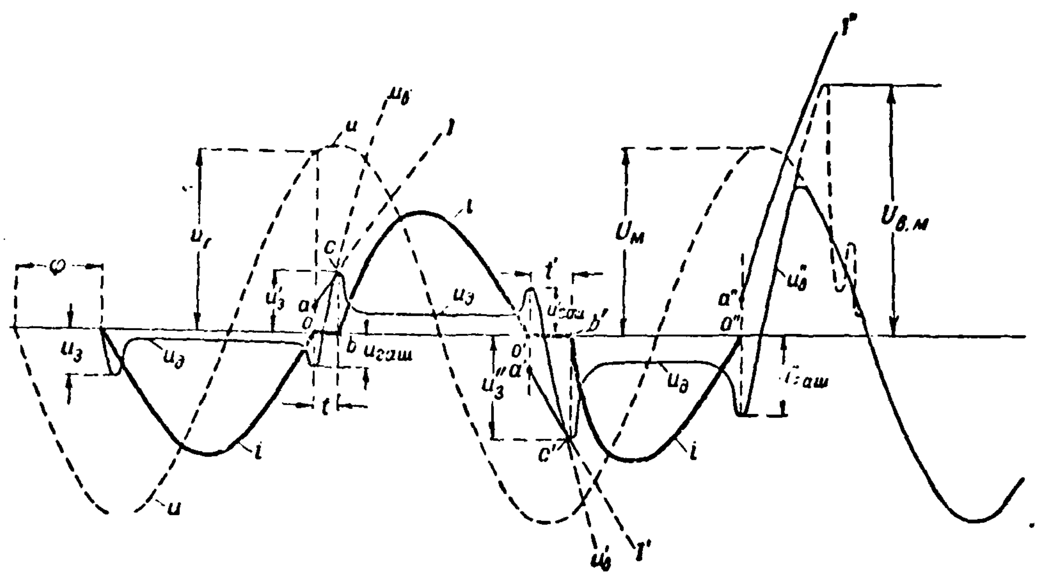

Fig. 13-17. Oscillogram of the cutoff/disconnection of alternating current circuit with inductive load (cos ϕ<1).

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If with the cutoff/disconnection of resistive load voltage on contacts was restored on the sinusoid of commercial frequency (Fig. 13-16), then with the cutoff/disconnection of the lagging current the restored voltage on the contacts of the switch is changed on certain curve $u_в$ (Fig. 13-17). At the moment of transiting the current through zero (moment/torque O) voltage on arc gap is equal to $u_{гаш}$ - to the voltage of arc extinction, and the voltage of source u_r

(generator) has opposite voltage and it is close to maximum value $U_м$.

Dielectric strength of gap/interval changes on the curve Oa1.

New repeated, by the test/sample of the gap/interval between the contacts of switch and striking of the arc they are possible, as noted above, only when the voltage on arc gap will be equal to the ignition voltage of arc. If after arc extinction voltage on arc gap instantly changed in direction and value and became equal to the instantaneous value of the voltage of source $u_г$, the repeated striking of the arc would occur immediately $(u_г > 0a)$. However, in actuality an instantaneous change in the voltage on arc gap is impossible as a result of the presence in network of certain inductance and capacity/capacitance (Fig. 13-18 conditionally shows concentrated L and C). Actually/really, any change in the voltage on arc gap is accompanied by a simultaneous change in the voltage also on the capacity/capacitance of network (in the simplest case, led on Fig. 13-18, $u_C = u_в$), in consequence of which in network appears the permittance current, which calls the loss of line voltage. In proportion to the charge of capacity/capacitance the current in network decreases, and consequently, decreases and the loss of line voltage - voltage on arc gap is restored. As soon as this restored voltage will achieve the value, equal to the ignition voltage of arc (moments/torques b and b' in Fig. 13-17), the arc again ignites and

burns to the following transition/junction of the current through zero, after which the described phenomena are repeated.

But if the restored voltage remains always of less than dielectric strength of gap/interval (curved 0" a" 1"), then, naturally, arc no longer is restored and the process of the work of switch concludes (moment/torque 0").

The more intense the deionization of arc gap, the steeper the change curved 0a1, 0'a'1', etc., and consequently, the longer the pause of current t, t' and so forth. With the amplification of the deionization of arc gap decreases the common duration of arcing in switch, which lightens its work.

The process of changing the value of voltage on arc gap from the value of the voltage of arc extinction $u_{гаш}$ to ignition voltage, if arc again ignites, or to the voltage of source, if arc repeatedly does not ignite, they call the process of resumption of voltage.

Voltage recovery rate on arc gap, so that follows from presented, it depends on L and C of network. With increase in L and C voltage recovery rate decreases. The greater voltage recovery rate, the less the pause t, t' and so forth. Consequently, an increase in voltage recovery rate leads to an increase of the common duration of

arcing in switch, which makes heavier its work.

Approximately average/mean voltage recovery rate in simplest lumped circuit (Fig. 13-18) can be determined by the formula:

$$\left(\frac{du}{dt}\right)_{\text{ср}} = \frac{u_{\text{г}} 10^{-6}}{\frac{\pi}{2}\sqrt{LC}} \ \overset{(1)}{[\text{в/мксек}]}, \qquad (13\text{-}1)$$

Key: (1). V/μs.

where $u_{\text{г}}$ - instantaneous value of the voltage of source at the moment of transiting the current through zero; $\pi/2\sqrt{LC}=T/4$ - fourth of period of oscillations of the restored voltage.

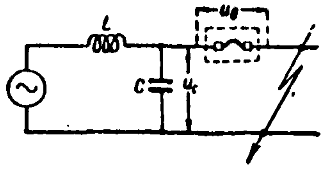

Fig. 13-18. Schematic of network with concentrated L and C.

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Let us note that voltage recovery rate depends also on the form of short circuit, state of arc gap, construction/design of arc-arresting device and series/row of other factors which we here examine cannot. Incomparably more complicated are the schematics of electrical networks. Therefore real average/mean voltage recovery rate can considerably differ from determined in formula (13-1). However, this formula gives clear representation about the effect of the parameters of circuit and value of the instantaneous value of voltage at the moment of arc extinction on the process of the work of switch.

With an increase in phase displacement ϕ increases the instantaneous value of the voltage of source u_r at the moment of transiting the current through zero and, consequently, also voltage recovery rate. It is obvious that maximum voltage recovery rate will be with the cutoff/disconnection of purely inductive short-circuit

current.

From all that has been previously stated, it follows that the switches, established/installed near the generators of station, with the cutoff/disconnection of short-circuit currents are located under more severe conditions in comparison with the switches, established/installed on the reducing substations, not only because then it is necessary to disrupt large in value short-circuit currents, but also because near generators voltage recovery rate more (less than L and C of short circuit).

Depending on the parameters of circuit the process of resumption of voltage on arc gap from moment/torque i=0 can occur aperiodically (unbroken curve u_{a}'' after moment/torque 0"), or periodically (dotted curve for the same half-period), which depends on the parameters of the disconnected circuit.

With periodic resumption of voltage the amplitude of restored voltage $U_{в.м}$ can 1.5-2 times exceed the amplitude of commercial-frequency voltage $U_{м}$.

From the examination of the curves of Fig. 13-17 it is evident that if we with aperiodic resumption of voltage after arc extinction at moment/torque 0" the arc are repeated cannot, then with periodic

resumption of voltage easily it can prove to be that the restored voltage will achieve the value of dielectric strength of gap/interval and the latter there will again be probit. By such, shape, with periodic resumption of voltage the duration of arc extinction in switch can substantially increase, which makes heavier the work of switch.

For guaranteeing the aperiodic character resumptions of voltage and facilitation of the work of switch apply the shunting of arc gaps by the effective resistance, similar of given in the diagram Fig. 13-14.

With a comparatively small value of backs-out resistor the current in the shunted arcs of fundamental disruptions (current $i-i$, in Fig. 13-14b) can be considerably reduced, which lightens their extinction. After the arc extinction of fundamental disruptions remains the current, flowing through backs-out resistor and supplementary disruption (4 in Fig. 13-14c). This current is comparatively small, since its value is limited by backs-out resistor, and it has considerable active component (cos ϕ is close to unity). Furthermore, since into the disconnected circuit consecutively/serially prove to be connected active backs-out resistor, is provided the aperiodic character of resumption of voltage on supplementary contacts at the moments of transiting the

current through zero. All this, as it appears of that presented earlier, it lightens and accelerates arc extinction in switch.

The shunting resistors improve the work of switches with the cutoff/disconnection of the low currents: charging rates of the unloaded electric power lines, running-light currents of powerful/thick high-voltage transformers, about which for greater detail, see [13-1].

It was above assumed (oscillogram of Fig. 13-16 and 13-17) that the arc goes out at current zero. However, during the very energetic deionization of arc it can break itself and somewhat earlier than current zero, thanks to which is increased the pause of current, and consequently, is facilitated arc extinction in switch. At the same time with a forced change of the current to zero in installation is unavoidable the onset of the overvoltages (as with the cutoff/disconnection of the direct-current circuits) whose value is greater, the more rapid it changes that to zero (the more di/dt) and the greater inductance of circuit.

In conclusion let us note that in some types of safety fuses with the very energetic deionization of arc the short-circuit current after melting by smelting insert breaks itself not at the moment of its zero value, but considerably earlier, than short-circuit current

it reaches impact value. It is logical that also in this case in installation appear the overvoltages. In more detail the work of these fuses is examined in following chapter 14.

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Chapter Fourteen.

SAFETY FUSES.

14-1. General information.

Safety fuses serve for the protection of electrical plants from the short-circuit currents and currents of overloadings. For operational inclusions/connections and cutoffs/disconnections of circuits consecutively/serially with safety devices/fuses are connected any switches, for example, knife switches.

Safety fuse in essence is of the metallic smelting of insert, its supporting contact device and housing. Many safety devices/fuses have also arc-control devices, which is formed with melting by smelting insert.

With an increase of the circuital current to the specific value the fuse link of fuse is heated to the melting point of metal and is

meltted (it burns out), disconnecting the handled or shortened/shorted out circuit. The greater the current, flowing through the fuse link, the more rapid it melts and is disconnected circuit.

The dependence of the tripping time of circuit as safety fuse on the strength of taking place through it current depict graphically, in the form the so-called shielding characteristics of safety fuse. Fig. 14-1 gives the characteristics of two safety devices/fuses with the fuse links to different rated currents $I_{вст1} < I_{вст2}$. With one and the same current, flowing through the fuse links, tripping time is the less the less the rated current smelting of insert.

Should be distinguished the rated current of safety device/fuse and rated current by smelting insert. By rated current of safety device/fuse is understood the current for which are calculated its current-carrying and contact parts, while for rated current by smelting insert - current, to which is calculated fuse link itself. In one and the same safety device/fuse usually it is possible to incorporate the fuse links to different rated currents.

With the how conveniently prolonged course of rated current the fuse link of safety device/fuse must not burn out.

The selection of safety fuses for the protection of electrical devices is examined in management/manuals on electrical networks [L. 7-1]. The shielding characteristics of safety devices/fuses accept according to the data of manufacturing plants.

Safety fuses must satisfy the following fundamental requirements: the reliability of operation, simplicity of design, small overall sizes, small cost/value, convenience in the operation.

If in network/grid are established/installed several series-connected fuses, then during short circuit in any element/cell of network/grid or with its overloading must burn out the safety device/fuse, which shields this element/cell. By this is provided the steadiness of the work of the remaining elements/cells of network/grid. For the explanation of the aforesaid let us examine the diagram of station (Fig. 14-2) the low voltage of small power with safety fuses established/installed on generator and waste/exiting lines. The current of the load of the waste/exiting line is always less than the rated current of generator, since each generator usually supplies several waste/exiting lines. Therefore rated current by smelting the insert of fuse 1 of line is less than the rated current by smelting insert of the safety device/fuse of 2 generators ($I_{вст2} > I_{вст1}$).

Let us assume that the shielding characteristics of the fuse links indicated are given in Fig. 14-1 (with respect 1 and 2).

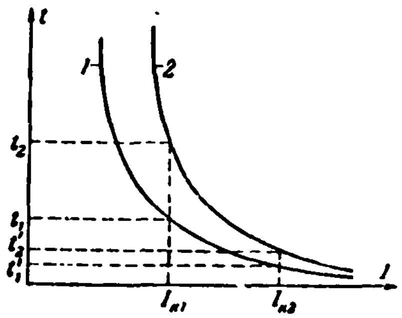

Fig. 14-1. Shielding characteristics of the fuse links.

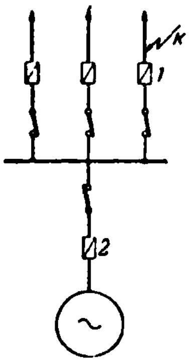

Fig. 14-2. Arrangement/position of safety fuses in circuits of station of low voltage of small power.

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If with which closing/shorting at point K current $I_{\kappa 1}$ is comparatively small, then it is possible with confidence to assert that will burn out the fuse link of safety device/fuse 1 and to disconnect the damaged line, since, judging by characteristics, tripping time t_1 is considerably less than the time t_2 of the cutoff/disconnection of circuit by fuse 2 with the same current.

Generators and other lines will continue to work normally.

With an increase in the short-circuit current this difference in the time of the burn-out of two series-connected safety devices/fuses decreases also with high currents, for example, with current I_{K2} the difference between t'_1 and t'_2 becomes small and already there is no confidence, which during short circuit at point K will compulsorily operate/actuate safety device/fuse 1 of line. Actually/really, if the fuse link of the safety device/fuse of 2 generators had during the normal mode of work the temperature more than normal or any mechanical defects (scratches, fractures, hollows and, the like), then it can burn out earlier than will burn out the fuse link of fuse of line. Because of this will be ended the feed of all waste/exiting lines of station. In the first of the examined cases fuse 1 it disconnected circuit selectively, and in the second case fuse 2 it operated/actuated nonselectively. By the selective action of fuses is understood the burn-out only of that safety device/fuse, which is nearest to the place of short circuit.

Therefore upon series connection into the circuit of several safety devices/fuses one should check according to their characteristics, will be provided their selective action with maximum possible short-circuit current in this installation. If are installed uniform safety devices/fuses with the fuse links from identical

material, then for guaranteeing the selectivity of their action it is necessary that the rated currents of the fuse links of the series-connected safety devices/fuses it would differ from each other, as far as possible, to two steps/stages of the scale of the rated currents (see Table P-12).

The characteristics of the fuse links are very unstable - the fuse melting time strongly depends on the state of circuit contacts and by the very smelting of insert. If contact surfaces are badly/poorly matched and strongly oxidized, if contact screws are badly/poorly tightened, then as a result of increased contact resistance of contacts they overheat both contact system of safety device/fuse and its fuse link. The strong overheating of the latter can lead to its nonselective burn-out with short circuits and overloadings and to its even burn-out with the current of less than the nominal. Then is possible as a result of the high temperature of surrounding air and the so-called "ageing" of the metal of insert - in the course of time the surface of insert is oxidized and its useful section decreases. Latter/last phenomenon manifests itself especially sharply, if in operation insert frequently overheats.

The tripping time of circuit by safety fuse depends also on the metal from which is prepared the fuse link, and the type of the used arc-suppression device/equipment. The more ideal the arc-suppression

device/equipment, the more current it can disconnect safety device/fuse. That maximum current which safety device/fuse can disconnect without any strains, which block its further exact work after the exchange by smelting insert, call limiting current the cutoffs/disconnections of safety device/fuse ($I_{\text{отк.пр}}$). Cutoff/disconnection by fuse of larger current can lead to its decomposition, and possibly also to arc-over of shortly adjacent phases.

Drawback of safety devices/fuses is also the need of exchanging the fuse links after their burn-out. Let us incidentally note the inadmissibility of the use/application of the "homemade" inserts whose characteristics can sharply differ from the characteristics of the inserts of in-house production. The use/application of homemade inserts leads frequently to the nonselective cutoffs/disconnections of circuits and the disturbance/breakdown of the nourishment of users.

The fuse links of safety devices/fuses are manufactured from lead, alloys of lead with tin, zinc, aluminum, copper, silver and some other metals.

Lead, alloys of lead with tin, zinc have comparatively low melting point (with respect 327, 200 and 420°C) and small electrical

conductivity. Therefore the section of the fuse links from these metals is obtained considerable, especially with large rated currents. Such inserts are applied only in fuses to 500 in inclusively. Zinc inserts are better than lead ones, since they are less oxidized by atmospheric oxygen (is less ageing), and therefore possess more stable characteristics.

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In safety devices/fuses by voltage higher than 1000 V massive fuse links are not applied, since forming under the action of arc vapors of metal impede the process of its extinction (chapter 13). Massive inserts are undesirable also in the open safety devices/fuses, since in this case with blowing occurs the sputtering of the large mass of molten metal, which is dangerous for the service personnel and the nearest equipment.

Copper and silver possess high electrical conductivity and considerable melting point: with respect to 1080 and 960°C. Large advantage of copper and silver inserts - small section. Copper inserts had extensive application in safety devices/fuses to all voltages do and higher than 1000 V. So that copper of insert would not be oxidized by atmospheric oxygen, are applied tinplated, but with small sections also silver-plated copper inserts. Such inserts

are less subjected to ageing and possess more stable shielding characteristics.

The silver inserts of way; therefore them apply mainly in safety devices/fuses by voltage higher 1000 V by small rated currents. In safety devices/fuses for the protection of voltage transformers whose operating currents are very small, are applied also fuse links of constantan or Nichrome.

An essential deficiency/lack in the copper and silver fuse links is comparatively high temperature of their melting. With prolonged course through the safety device/fuse of current, somewhat smaller current, which melts insert, copper or silver inserts can long, without being meltted, to be heated to temperature of 900°C and even somewhat larger. So high and prolonged a heating of the fuse links can lead to the excessive overheating of contact system and housing of safety device/fuse, especially closed safety devices/fuses, which can be the reason for their decomposition.

Therefore in the closed safety devices/fuses with silver and copper inserts apply artificial methods decreases in the melting point of inserts. By simplest and rational method is deposition on wires smelting the insert of metallic solvent in the form of the soldered on on them small balls/spheres from tin or lead. During

heating by smelting insert to the melting point of tin or lead on by smelting to insert are formed drops of molten tin or lead. Molten tin or lead dissolves in itself the more high-melting metal of insert (copper, silver), as a result of which the insert in the place of the deposition of balls/spheres breaks down itself and is disrupted. Forming in the place of disruption arc melts insert all its over length.

Thus, during the use/application of metallic solvents it is possible to obtain the inserts of a small section at a melting point, a little which exceeds the melting point of tin or lead, thanks to which is facilitated the arc extinction (it is small vapors of metal) and is removed the danger of overheating housing and contact system of safety device/fuse with its prolonged overloading. The ball/sphere of solvent virtually does not affect the process of melting by smelting insert by short-circuit current.

Advantages of the safety fuses: comparatively small cost/value, simplicity of device/equipment and maintenance/servicing, small sizes/dimensions.

Great use/application safety fuses were obtained in installations by voltage to 1000 V inclusively. In the installations of high voltage to 10-45 kV and rarely above safety fuses are applied

for the protection of low-power radial networks/grids, small transformer substations and in some other cases. Are used extensively safety devices/fuses for the protection of voltage transformers.

14-2. Constructions/designs of safety devices/fuses.

The simplest safety devices/fuses for installations voltage to 1000 V are safety devices/fuses lamellar and stopper.

Lamellar safety devices/fuses do not have arc-suppression devices/equipment and therefore they are capable of disrupting very small short-circuit currents. With the melting of these safety devices/fuses is formed the open arc and proceeds the sputtering of molten metal and propagation in different directions from the safety device/fuse of incandescent and ionized gases, which is dangerous for the service personnel and the surrounding electrical equipment. Therefore in new installations lamellar safety devices/fuses do not apply.

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Stopper safety devices/fuses are used extensively for the protection of electrical illuminating installations and electric motors of small power by voltage to 380 V (more rarely, 500 V). Their

advantage in the fact that the plug is unscrewed without touch to parts, which are located under voltage, and the exchange by smelting insert is possible only with the unscrewed plug.

Safety devices/fuses with the open porcelain tubes earlier were used extensively in the installations of all voltages to 35 kV inclusively.

In these safety devices/fuses the fuse link is passed inside of the open from ends/faces porcelain tube and is secured by screws/propellers to clamps at the ends/leads of this tube. With the melting of insert and striking of the arc the pressure within tube increases as a result of the appearance of vapors of metal and strong heating of the trapped in the tube air. Forming gases and expanded air are blown out upward and downward from the open ends/leads of the tube - appears the longitudinal gas blast, which deionizes and which quenches an arc. However, the effectiveness of this blast is small as a result of a small quantity and the small gas pressure in tube and, consequently, also the low speed of gases, but so as a result of use for blast and deionization of the arc of the ionized and heated gases. Therefore these safety devices/fuses can disrupt only small short-circuit currents and their disconnecting ability is completely insufficient for contemporary powerful/thick power systems.

A deficiency/lack in these safety devices/fuses is also the fact that with burn-out by smelting insert from the open ends/leads of the tube are rejected up to considerable distance the splashes of molten metal and incandescent ionized gases which are dangerous for the service personnel and the surrounding electrical equipment.

At present fuses with the open tubes does not apply.

Horny safety devices/fuses are also one of the old constructions/designs of high-voltage safety fuses for external installation. In them the fuse link is fastened at the bend of the metallic horns, established/installed on stand-off insulators. With burn-out by smelting insert the arc overlaps the gap/interval between horns and under the effect of electrodynamic forces and flow of warm air it rises upward. Passing through air, arc is cooled, it is deionized and goes out. The form of horns leads to an increase in the arc length in proportion to lift it upward. Deficiencies/lacks in the horny safety devices/fuses: slow arc extinction, propagation of arc to the high altitude above horns, small disconnecting ability.

At present these safety devices/fuses are applied rarely and only in external installations by voltage to 35 kV inclusively.

Safety devices/fuses with the closed fiber tubes of the type PR

are applied in the installations of direct and alternating current by voltage to 500 V inclusively, also, to rated currents to 1000 A.

Fig. 14-3 gives the section/cut of receptacle, while in Fig. 14-4 the general view of a safety device/fuse of the type PR-2. At both ends/leads of fiber tube 1 are screwed brass caps/hoods 3, which fasten contact knives 4, to which by bolts 5 is attached zinc fuse link 6. Knives 4 throw in themselves into motionless spring contacts 7, adjusted on insulating plate/slab 8.

The safety devices/fuses to rated currents to 60 A contact of knives 4 do not have and brass caps/hoods 3 are simultaneously the contacts, notched into the motionless contact springs of 7 corresponding forms.

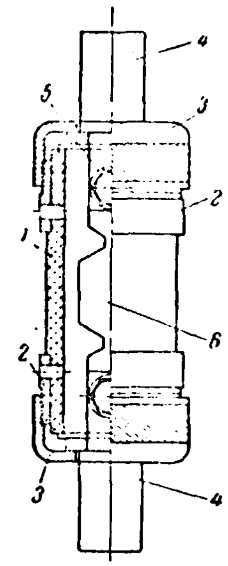

Fig. 14-3. Receptacle of fuse of the type PR-2.

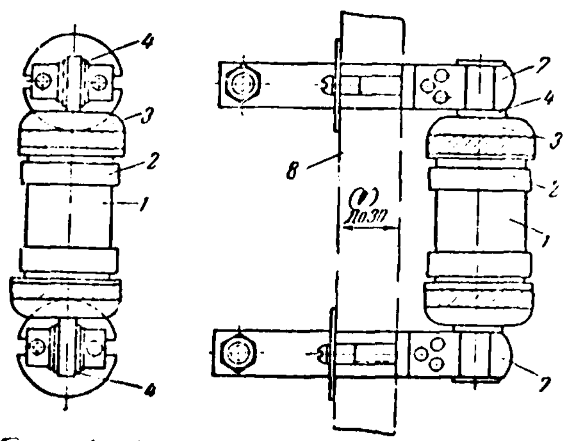

Fig. 14-4.

Fig. 14-4 . Safety device/fuse tubular of type PR-2 on 100-350 A, to 500 V.

Key: (1). to.

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In safety devices/fuses of the type PR are applied the figure lamellar zinc inserts, which take 2-4 narrowed place (Fig. 14-3 and 14-5). In the narrowed places of insert is separated/liberated more heat, than in wide parts, since their electrical resistance is more. In normal mode the heat, which separates in the drafts of the insert, is abstracted/removed because of thermal conductivity to the less heated wide parts of the insert and to the contact knives, of which it is scattered into the environment. The most heated region is located in the places of transition/junction from narrow to wide part insert. In one of these most heated places is meltted the fuse link with the currents of overload (Fig. 14-5b).

During short circuits the current, flowing on by smelting to insert, grows/rises very rapidly; therefore the large quantity of heat, which separates in the narrow sections of the insert, does not manage to be abstracted/removed and insert is meltted virtually simultaneously in all bottlenecks as is evident in Fig. 14-5c.

The duration of arcing in safety device/fuse with the disruption of short-circuit current composes a total of several thousandths of a second, for which the separated/liberated wide part by smelting insert manages to move for the insignificant part of the millimeter [L. 14-1]. Therefore in the examination of the work of safety device/fuse with the cutoff/disconnection of short-circuit current one should consider that the separated/liberated wide parts of the insert continue to hover and in the receptacle of safety device/fuse appears multiple break with a number of consecutively/serially burning arcs, the equal to a number of bottlenecks smelting of insert (two in safety devices/fuses on 250 V ~~int~~o four in safety devices/fuses to 500 V ~~¢~~). This separation of arc into several short arcs, which burn between massive wide parts by smelting insert, contributes to arc extinction just as its separation into the series/row of short arcs in arc-suppression grating with the metallic plates (see §13-2).

The fiber from which is made the tube of receptacle, is gas-generating material. With burn-out by smelting insert and formation of arc under the action of its high temperature certain quantity of fiber passes into gaseous state. Fiber allots approximately/exemplarily 40o/o of hydrogen, 50o/o of carbon dioxide and 10o/o of water vapor; all these gases possess the high

arc-arresting properties (see §13-2).

Furthermore, evaporates the part of zinc from which is made the fuse link.

Since the receptacle of safety device/fuse is closed and its space is small, then because of the generation of gases, and especially as a result of the considerable heating of gases by arc, pressure in receptacle greatly rapidly grows/rises and the greater, the greater the disconnected current. With the cutoff/disconnection of short-circuit current the pressure in the receptacles of some safety devices/fuses of the type PR-2 reaches 100 atm(gage) and even higher (receptacles have approximately/exemplarily dual safety factor).

In §13-2 it was indicated that with an increase in the gas pressure the deionization of arc is amplified and the voltage, necessary for its maintenance, increases. The deionization of arc substantially contributes and the high arc-arresting properties of gases in receptacle. The vapors of metal impede the deionization of arc, but them in receptacle comparatively a little, since evaporates only a small fraction of the insert (Fig. 14-5).

With the cutoff/disconnection of short-circuit current because

of the energetic deionization of arc its resistor/resistance so rapidly and considerably increases that the short-circuit current in circuit forced decreases to zero earlier, rather than in alternating current circuit it will achieve impact value, and in direct-current circuit - the steady value.

A change in the current and voltage in the simplest alternating current circuit (Fig. 14-6a) with cutoff/disconnection by its safety device/fuse of the type PR is shown in Fig. 14-6b, where u and i - a phase voltage and the current of the circuit, in which are established/installed the safety devices/fuses. Short circuit occurs at moment/torque O. Dotted line shows, as would change short-circuit current i_k in circuit in the absence in it of safety devices/fuses.

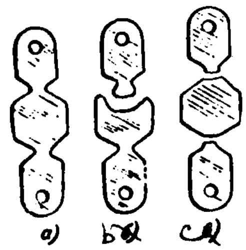

Fig. 14-5. Zinc fusible insert of safety devices/fuses of the type PR to 200A, 250 V. a) the insert, which did not burn out; b) the insert, burning out with the overloading; c) the insert, which burned out during short circuit.

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For time t_1 the circuital current increases and fusible insert is heated. On the achievement by the current of value i the insert is melted and appear arcs in all its molten bottlenecks. As a result of a rapid increase of the resistor/resistance of these arcs the circuital current decreases to zero. Time t - this is the tripping time of circuit by safety device/fuse (about 0.01 s). Thus, short-circuit current does not reach its maximum impact value i_y; safety device/fuse limits circuital current by value i. Such safety devices/fuses are called current-limiting. Their disconnecting ability is great: with voltage 380 V it reaches 23 kA (effective value).

During the use/application of such safety devices/fuses considerably is facilitated the work of electrical equipment during short circuits. Virtually the electrical equipment, shielded by these safety devices/fuses, it is possible not to check against the actions of short-circuit currents.

The rapid forced change in the current causes (see §13-3) induction in the inductance of the disconnected circuit of emf, which is superimposed on line voltage, as a result of which appear the overvoltages. The more rapid changes the current and the greater the inductance of circuit, the greater the overvoltage. In Fig. 14-6b it is evident that at the moment of short circuit the line voltage decreased to zero, and then after the onset in the safety device/fuse of arc sharply increased, after achieving certain maximum value $U_{пер.макс}$. After arc extinction (i=0) the line voltage becomes newly normal.

On construction/design by smelting insert and receptacle of safety device/fuse depends the intensity of the deionization of arc and, consequently, also the value of overvoltage. Soviet safety devices/fuses with the closed fiber tubes are carried out so that the appearing overvoltages are not dangerous for electrical equipment of

those installations where them are applied (to 500 V inclusively).

The use/application of zinc fuse links in fuses PR is explained by their not only indicated above advantages in comparison with inserts from lead and from its alloys with tin. High value has that the fact that during the use/application of a zinc insert the temperature within tube in operation cannot be higher than melting point of zinc, equal to 420°C. With copper inserts the temperature within tube long can be close to the melting point of copper, i.e., about 1080°C, which can lead to the strong charring of the internal surface of fiber tube and the damage of the insulation of lead wires.

To advantages of safety devices/fuses with the closed tubes should be also related greater safety for the service personnel and possibility of the more compact location of equipment on the distributing frames and assemblies.

Safety devices/fuses with fine-grained filler received in recent years very wide acceptance in the electrical devices of all voltages to 35 kV inclusively.

The receptacles of these safety devices/fuses are performed from closed from both ends/faces of tubes from insulation. The fuse link is located within the receptacle, filled with any fine-grained

insulation, usually by quartz sand. Therefore during functioning of these safety devices/fuses of them are not rejected flame and ionized gases, which simplifies their installation in distributors and raises the safety of maintenance/servicing. Work they noiselessly.

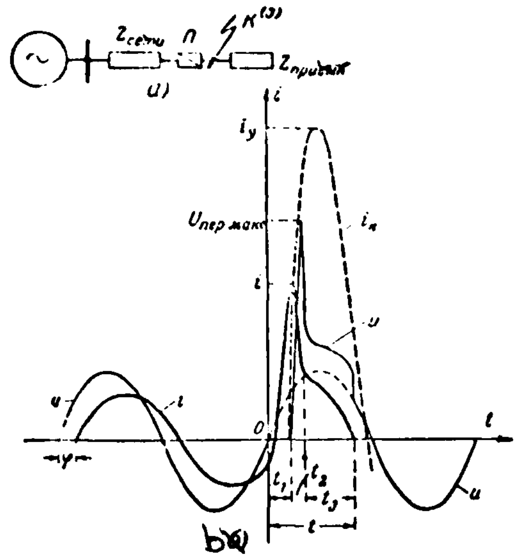

Fig. 14-6. Curved changes in the current and voltage with cutoff/disconnection by the current-limiting safety device/fuse of alternating current circuit during short circuit.

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With the melting of insert the arc burns in the channel of a small diameter, formed by the body of the vaporized by smelting insert. The intimate contact of arc with the surrounding filler amplifies the deionization of arc. In §13-2 it was indicated that for arc maintenance in the channel of a small diameter is required the considerably higher electric intensity, rather than for the freely burning arc.

The intensity of arc extinction in safety device/fuse with filler depends on section, length and material by smelting insert, and also on the material of filler and size of its grains. A good filler is pure/clean quartz sand. With granular filler incandescent and ionized gases, which are formed after evaporation by smelting insert, penetrate the gaps/intervals between grains of filler and, being contacted with the surface of the latter, they are deionized. The vapors of metal are condensed. Therefore decreases a quantity of ionized particles and vapors of metal in the channel, formed by the body of the vaporized by smelting insert, which facilitates and accelerates arc extinction.

With large cross section by smelting insert, and consequently, with a large diameter of channel and a large quantity of vapors of metal, which are formed after evaporation by smelting insert, the arc extinction becomes difficult as a result of its insufficiently intense deionization. Therefore the fuse links of quartz safety devices/fuses are performed from copper, silver, constantan.

The fuse links of quartz safety devices/fuses are performed of one or several parallel wires; as a result of the best cooling of thin wires the overall section of insert is less. With several

parallel wires the arc appears in several parallel channels of a small diameter, which facilitates its extinction (less than vapors of metal, better cooling arc, more intense recombination and diffusion of the charged/loaded particles, use of larger space of filler).

For warning/preventing overheating receptacle with the prolonged overloading of fuse, which is not accompanied by melting by smelting the inserts, will deposit to the fuse links solvents in the form of the tin or lead balls/spheres (see above).

Filler absorbs the significant part of the energy of arc; therefore pressure in quartz safety devices/fuses is considerably less, rather than in safety devices/fuses with closed fiber tubes with the same of voltage and the same disconnected current.

If through the quartz safety device/fuse flows/occurs/lasts the current of overloading, then the fuse link first is meltted and is disrupted in the places of the imposition of solvent. Forming arc melts then insert all over length. Arc finally goes out into one of the moments/torques of transiting the current through zero, when the speed of an increase in dielectric strength of gap/interval proves to be more than the rate of the increase of the restored in gap/interval voltage.

With course through the safety device/fuse of short-circuit current thin fuse link almost instantly is meltted and evaporates all over length. Pressure in channel is raised, the vapors of metal are splashed the sides and penetrate the depth of quartz sand where they condense on its particles.

Since the appearing at moment/torque evaporations by smelting insert vapors of metal are weakly ionized, the resistor/resistance of arc gap proves to be considerable and circuital current sharply decreases (time t_2 in Fig. 14-6). Simultaneously in circuit appears the overvoltage, which reaches maximum value $U_{\text{пер макс}}$. This overvoltage, which considerably exceeds normal line voltage, supports the arc, which burns in the weakly ionized narrow channel within filler. Further due to thermal ionization the resistor/resistance of arc gap grows/rises already somewhat slower, in consequence of which rate of change in the current also becomes less - current changes to zero, but it is considerably slower (time t_3 in Fig. 14-6). Respectively decreases the voltage, necessary for arc maintenance and, consequently, also the value of overvoltage. After time t after the beginning of short circuit the cutoff/disconnection of circuit ends and overvoltage was discontinued - line voltage is again equal normal.

From that presented it is evident that, as safety devices/fuses

of the type PR, quartz safety devices/fuses are the current-limiting apparatuses.

The value of the overvoltage, which appears with the burn-out of quartz safety device/fuse, depends on the length of insert. The greater the length of insert, i.e., the greater the length of channel at the moment of evaporating the insert, the higher the voltage necessary for arc maintenance in this channel, the greater the value of overvoltage.

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The length of the fuse links of safety devices/fuses to voltages to 500 V is inclusively small; therefore also the overvoltages, which appear with their burn-out, are comparatively small and dangerous for insulation electrical equipment of the installations of these voltages.

In contrast to this the fuse links of quartz safety devices/fuses by voltages of higher than 1000 V have large length, therefore, if are not accepted special measures, overvoltages with their burn-out during short circuits can reach value to 4.5 U_{ϕ}, which is already dangerous for the insulation of electrical equipment.

By the simplest method, which limits the value of the overvoltages indicated, is use/application the stepped smelting of the insert, comprised along the length of two wires of different section. In this case initially is meltted and evaporates the part of the insert in section with smaller section. Appearing in this case overvoltage will be less as a result of the smaller length of channel, in which initially burns the arc. Further is meltted the second section of the insert of larger section, and arc is dilated/extended to full/total/complete calculated length. As a result of entire this circuital current decreases somewhat slower and overvoltage does not exceed (2-2.5) U_{ϕ}. In spite of certain artificial delay/retarding/deceleration of process, time t of the cutoff/disconnection of circuit with the large multiplicities of short-circuit current remains very small, order 0.005-0.008 s.

The same results they reach, supplying safety device/fuse with auxiliary insert with discharger. In the middle of this insert, into its crosscut, they insert the porcelain ring, in which are secured its ends. The section of auxiliary insert on both sides of porcelain ring is taken different (on the one hand section two times more - two twisted together wires).

After the burn-out of working insert the voltage increases, and when overvoltage achieves certain value, discharger of auxiliary insert breaks down and the disconnected current begins to flow/occur/last through the auxiliary insert which burns out as stepped, and is disconnected circuit.

For installations to 500 V inclusively Soviet plants manufacture quartz fuses of the type PN2 with dismountable receptacles to rated currents 100-600 A and type NPN with noncollapsable receptacles on 15 and 60 A. The receptacles of safety devices/fuses of the type NPN are not subject to overcharging and with burn-out must be replaced by new ones [L. 14-2].

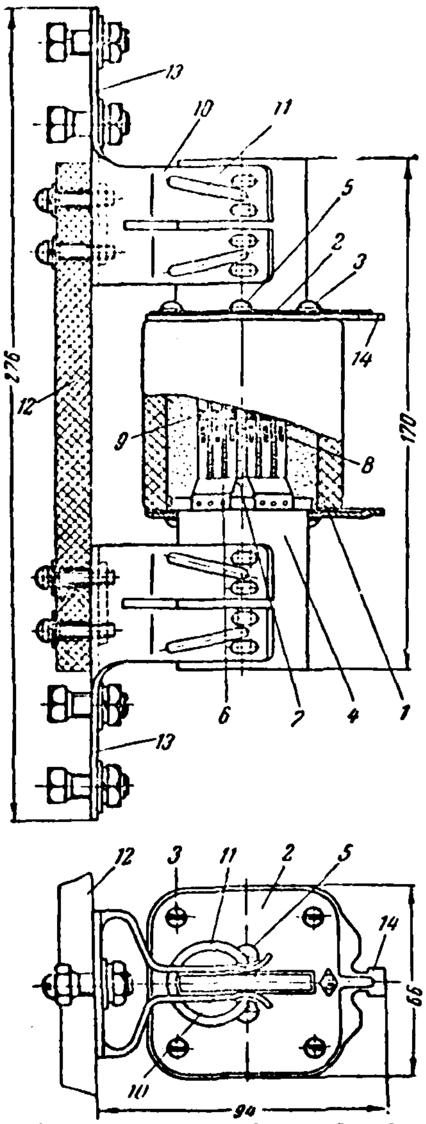

Fig. 14-7. Safety device/fuse of the type PN2-400 on 400 A, 500 V.

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Fig. 14-7 shows fuse of the type PN2-400 to rated current 400 A. The receptacle of fuse consists of square porcelain tube 1 with circular central opening/aperture, two metallic covers/caps 2, fixed

by screws/propellers 3 to the ends/faces of the porcelain tube of which for this there are openings/apertures with cutting, two contact knives 4, fixed by screws/propellers 5 to covers/caps 2, and fuse links 6, fastened/strengthened to knives 4. The internal cavity of receptacle is filled with dry quartz sand 7.

The fuse links are stamped from thin copper tape. During short circuits the plates of insert are meltted in bottlenecks for 8.

On the middle part of the plates of insert is soldered on tin 9 (solvent). In these places the plates are meltted with the currents of overloading.

The contact knives of receptacle throw in themselves into stamped/die-forged copper contact struts 10, fastened/strengthened to insulating plate/slab 12. Pressure in contacts create steel snap rings 11.

Terminals/grippers 13 serve for the connection of busbars or wires.

The receptacles of safety devices/fuses can be inserted and extracted with the aid of detachable plastic knob/arm/handle (Fig. 14-8). On the covers/caps of the receptacle of safety device/fuse are

T-shaped struts 14 (Fig. 14-7), which introduce into the appropriate sockets of knob/arm/handle with process/operations with receptacle. The use/application of detachable knobs/arms/handles provides the safety of process/operations with receptacles, which are located under voltage.

The maximum disconnected current of fuses of the type PN2 with voltage 500 V is 25-50 kA depending on the rated current of receptacle.

For installations by the voltage of above 1000 V Soviet plants manufacture the quartz safety devices/fuses of types PK and PKT.

Safety devices/fuses of the type PK are intended for the protection of power branch circuits to 35 kV. They are manufactured to rated currents to 400 A. Safety devices/fuses of the type PKT are intended for the protection of voltage transformers to 35 kV. The fundamental characteristics of quartz safety devices/fuses are given in table P-12.

Fig. 14-9 gives the receptacles of quartz safety devices/fuses to rated current to 7.5 A (Fig. 14-9a) and 10A and more (Fig. 14-9b). Receptacle consists of porcelain tube 1, reinforced by caps/hoods 2. Inside tube is inserted fuse link 5. The latter/last in safety

devices/fuses to rated currents to 7.5A it is wound around ceramic core 4. After assembly and charging by dry quartz sand 7 receptacle is closed by covers/caps 3 and hermetically is solderred.

The fuse links are made from several parallel copper silver-plated wires with soldered on on them tin balls/spheres 6.

Within receptacle passes steel indicating insert 8, one end/lead connected with hook of small armature of the indicator of functioning 9. With the course of the short-circuit current or current the overloadings are meltted both workers and indicating of insert. The burn-out of the latter frees/releases reed 9, which is ejected by outside spiral spring.

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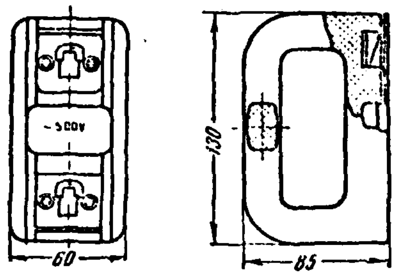

Fig. 14-8. Detachable knob/arm/handle for the installation of the receptacles of safety devices/fuses of the type PN2.

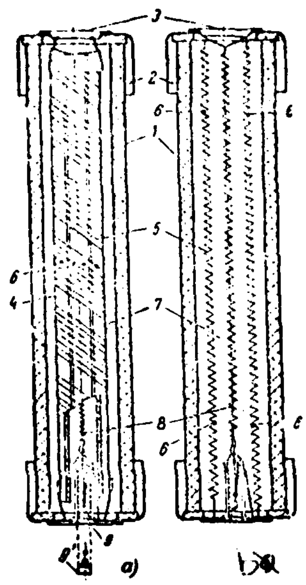

Fig. 14-9. Receptacles of quartz safety devices/fuses of high voltage. a- ~~e by~~ with smelting by insert on the ceramic core; b) with spiral fuse links.

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The general view of a safety device/fuse of the type PK-10 on 10 kV and 30A is shown in Fig. 14-10.

The fuse links of safety devices/fuses of the type PKT to voltage transformers are performed of one constantan wire, wound around ceramic core. These safety devices/fuses do not have indicators of functioning; therefore about their burn-out they judge by the absence of readings of the corresponding instruments, connected into the secondary circuit of voltage transformer.

Safety devices/fuses with the open tubes from gas-generating material of the type PSN (safety device/fuse shooting of external installation) are intended for external installations by voltage 10-35-110 kV (table P-12). Fig. 14-11 shows receptacle, while in Fig. 14-12 the general view of fuse of the type PSN-35 on 35 kV.

Fuse link 3 (Fig. 14-11) is placed in the metallic cap of 5 receptacles and is connected with flex conductor 2, that passes within tube 1 of gas-generating material (PVC plastic). Flex conductor 2 concludes with tag 4.

In the operating position of safety device/fuse (Fig. 14-12) the

metallic cap of receptacle 1 is jammed in holder on upper pin insulator 2. On lower pin insulator 3 on axis 6 is established/installed contact knife 5, equipped with the helical spring, which attempts to turn it to position 5'. The knife indicated encompasses the neck of tag 4.

With burn-out with smelting insert contact knife begins to rotate and extracts flex conductor from receptacle. In this case the arc, initially with the melting of insert forming in the metallic cap of receptacle, is pulled inside the gas-generating tube - occurs abundant liberation of gas, pressure within receptacle rapidly is raised (it reaches 100-120 atm(gage)) and appears longitudinal blast. Arc energetically is deionized and goes out. The greater the disconnected current, the more energetic the blast, the more rapid goes out the arc. With the cutoff/disconnection of short-circuit currents production time is the similar fuses less than one half-period.

Is analogous the device/equipment of safety devices/fuses on 10 and 110 kV.

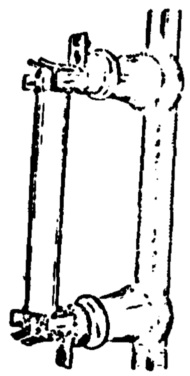

Fig. 14-10. Quartz safety device/fuse of the type PK 10/30 on 10 kV, 30a.

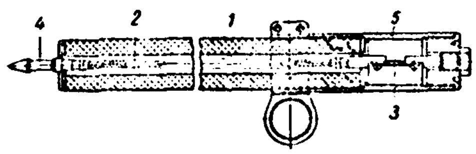

Fig. 14-11. Receptacle of safety device/fuse of type PNS-35 on 35 kV.

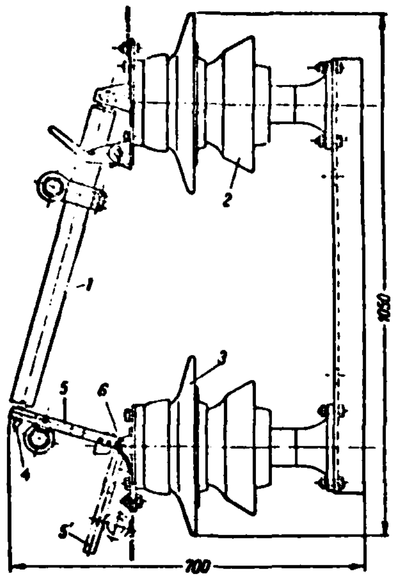

Fig. 14-12. Safety device/fuse of type PSN-35 on 35 kV.

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Chapter fifteen .

Switches with voltage to 1000 V.

15-1. Air non-automatic breakers.

Knife switches are simplest air circuit breakers, which use for nonautomatic connection and disconnection of the circuits of direct and alternating current with voltage to 500 V inclusively. Usually them are applied to rated currents to 1000 A; to high currents the knife switches are applied comparatively rarely and mainly in installations of direct current. In the diagram of Fig. 3-2 knife switches are shown on the lines of their own needs by voltage 380/220 V.

During the use/application of knife switches additionally to them are installed the safety fuses, which use for the automatic cutoff/disconnection of circuits with short circuits and

overloadings.

The pole of knife switch (Fig. 15-1) consists of two fixed contacts 1 and 2, fastened/strengthened to plate/slab 3 of insulation, and knife 4, which rotates on axle 5, fastened/strengthened in back contact 2. Dotted line showed the position of knife with the connected knife switch. In the connected position the knife throws in itself between the struts of the fixed contacts which can be carried out on one of the types, shown in Fig. 12-8. Handle 6 serves for inclusion and cutoff/disconnection of knife switch.

With the cutoff/disconnection of circuit under the current between knife 4 and fixed contact 1 appears electric arc 7, which must be extinguished. They previously considered that the fundamental effect on the process of arc extinction in air with the cutoff/disconnection of knife switch has its mechanical extension. Therefore the old constructions/designs of knife switches were characterized by comparatively large length of knives and is greater, the greater the rated current of knife switch.

However, the investigations, carried out by Soviet scientists [L. 14-1 and 15-1], showed that this position is correct only with cutoff/disconnection by the knife switch of direct-current circuits

at comparatively low values of the current of load - to 70-100 A, when actually arc goes out in essence due to its mechanical extension.

It was established/installed, that in the cutoff/disconnection of high currents ever more essential effect on the process of arc extinction exerts its motion in surrounding air, caused by the electrodynamic forces, which operate on the current, flowing in arc. The greater the current, the greater the intensity/strength of the created with it magnetic flux, the greater the operating on arc electrodynamic forces and the greater the speed of its motion in air. The rapid adjustment of arc in air causes its intense deionization (chapter 13); arc rapidly goes out also at small length. It turned out that with the cutoff/disconnection of direct current is more than 500-600 A the arc extinction in essence caused precisely by the motion of arc in air.

To the motion of arc upward contributes also moving in this direction of flow of the air, strongly heated by arc.

The operating on arc electrodynamic forces depend on the square of current and on the form of the outline over which flows/occurs/lasts the current. Assuming that in electric arc 7 (Fig. 15-1) tick I flows/occurs/lasts over the circular arc, described from

the axis 5 of rotation of knife with a radius of l, by the approximately/exemplarily equal to the length of knife 4, then force f, which operates on the unit of arc length and directed it is radial, it is possible to determine by the formula:

$$f \approx \frac{I^2}{4\pi l}\frac{dL}{dl}, \quad (15\text{-}1)$$

where L - inductance of outline.

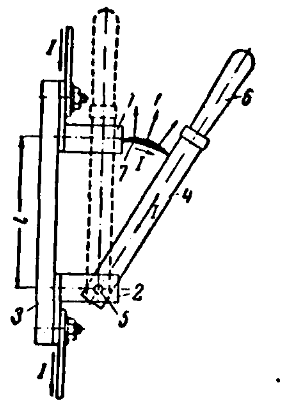

Fig. 15-1. The electrodynamic forces, which operate on arc with the cutoff/disconnection of knife switch.

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From formula (15-1) it is evident that with the decrease of the length of switch blade electrodynamic forces f, which operate on arc, increase, that also causes its pain rapid motion in air and, consequently, also its more energetic deionization.

Thus, with large rated currents it is expedient to decrease, but not to increase the length of knives of knife switch, as this they made earlier. At the same time it is clear that the minimum length of switch blades of those intended for installations of direct current, must be determined from the condit on of the reliable cutoff/disconnection of low currents to 75-100 A, when primary

meaning has the mechanical extension of arc.

However, with the cutoff/disconnection of the circuits of alternating current with voltage to 220 V inclusively as this was explained in chapter 13 arcs between the contacts of switch usually it goes out upon first transfer of the current through zero, even with the single-pole cutoff/disconnection of circuit 220 V, i.e., when to the contacts of knife switch proves to be applied all the voltage 220V. In this case the arc goes out in the presence of the very small disagreement of contacts (to 0.5-1 mm), with any disconnected current and virtually with any shift/shear between the current and voltage, right up to 90° [L. 14-1].

In three-phase installations with voltage 380 V apply tripolar knife switches with the simultaneous cutoff/disconnection of three phases; therefore the working conditions of knife switches in these installations approximately/exemplarily the same as with the single-pole cutoff/disconnection of branch circuits 220 V.

On the basis of the aforesaid, the length of switch blades, intended for installations of alternating current, practical is determined not of extinction conditions for electric arc, but from the conditions of cooling and mechanical strength of contacts, design considerations, etc.

All positions presented above are taken into consideration during the development of the constructions/designs of knife switches with the shortened knives which are at present manufactured with Soviet plants.

By design distinguish the knife switches one-, two- and tripolar, with the front/leading (Fig. 15-1 and 15-3) or rear (Fig. 15-2) connection of wires (busbars).

The knife switches, intended for setting on panels from insulation, are manufactured without foundations, and those intended for setting on metal constructions - on insulating plates/slabs.

Previously knife switches were fulfilled with the flat/plane springy contacts, similar to those shown in Fig. 12-8a-d about deficiencies/lacks in which it was indicated in chapter 12. Knife switches at present manufacture predominantly with the linear contacts, for example, similar to those given in Fig. 12-8d and 12-10 (knife switches 15-2 and 15-3) whose special features/peculiarities were presented in chapter 12.

The given in Fig. 15-1 simplest knife switch has only make

contacts, not shielded from the effect of electric arc. Such knife switches can be applied only in installations of alternating current by voltage to 220 V inclusively, when with their cutoff/disconnection arc does not appear.

For the protection of make contacts from fusing by their arc they supply knife switches with arcing contacts or caps - 8 in Fig. 15-2.

In installations of direct current with voltage 220 V and higher and installations of alternating current with voltage 380 and 500 V knife switches without arc-suppression devices/equipment can be utilized only for inclusion and cutoff/disconnection of circuits without load. If necessary the cutoffs/disconnections of the currents of load in the settings indicated apply the knife switches, equipped with small arc-suppression gratings with steel plates, similar to that shown in Fig. 13-12. It suffices to supply grating with several steel plates so that the arc would go out at the moment of the first transition/junction of the current through zero.

Using the method of control the knife switches are with central (Fig. 15-1 and 15-2) and lateral handles, intended for setting from the face of the distributing frames, and with riggings (Fig. 15-3), intended for back of panel mounting on metal frame.

Fig. 15-2 shows tripolar knife switch to rated current 1000 A with central handle, on insulating plate/slab. Each pole of knife switch consists of two contact struts 1 and 2 of rectangular cross sections, passed through plate/slab 3 (for the rear connection of wires). Contact knife consists of two bands 4, which from both sides encompass contact struts.

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Knives and contact struts are contacted along lines, for which on knives are pressed semicylindrical flanges - rectilinear 5 against upper strut 1 and circular against bottom, that ensures the stable position of knife of relatively lower jointed strut 2. Pressure between knives and struts is created by spring washers 6, arranged/located on jointed strut, and by steel springy clamp 7, which encompasses both bands of knife and that arranged/located on upper strut. With cutoff/disconnection arc appears between carbon arcing contacts 8. The knives of three phases are connected by insulating crosshead 9, to which is fastened/strengthened handle 10.

The same construction/design have knife switches on 600 A. The pole of knife switches to rated currents more than 1000 A usually

consist of the appropriate number of single-pole elements of the dismantled/selected construction/design to current 1000 A.

To currents to 400 A inclusively the knife switches with linear contacts have somewhat different construction/design - in them moving knives throw in themselves between two motionless contact struts, having semicylindrical flanges for the creation of linear contact.

According to safety conditions knife switches with central and lateral handles and open knives it is possible to apply in installations with voltage not more than 220 V. In installations 380 and 500 V it is compulsory, while in installations 220 V it is desirable to apply knife switch with protective housings or with riggings (Fig. 15-3).

In knife switches with rigging on the front of the panel of the distributing frame is established/installed only control lever of 6, and the contact part of knife switch 1 and 2, mounted on insulating plate/slab 3, is established/installed on the metal frame from behind of panelboard. Control lever and contact knives are connected with the aid of controllable rod 5.

Switches. Everything said above in the relation to knife switches is entirely related also to switches. In off position the

knives of switch occupy the horizontal position in which they are held by special attachment.

Together with knife switches and switches in installations with voltage to 1000 V wide application obtained also the rotary switches, which were being characterized by large compactness and reliability of operation.

In recent years are spread also the combined apparatuses, in which are structurally/constructurally united the knife switches and the safety fuses whose use/application makes it possible to substantially shorten the dimensions of the cubic switchboards (see Vol. 2, chapter 8).

15-2. Automatic air switches (automata).

Automata are applied in settings of alternating current with voltage to 500 V inclusively, and in installations of direct current and large voltages. Autcmata have special attachments for the automatic cutoff/disconnection of the shielded parts of the installation with their overloading and during short circuits in them, and sometimes additionally and upon disappearance or with decrease in the voltage.

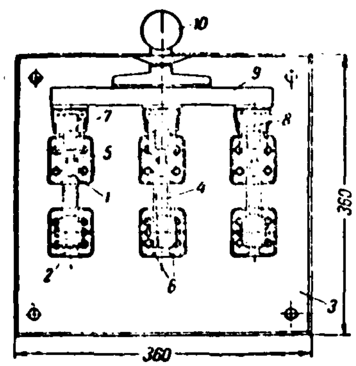

Fig. 15-2.

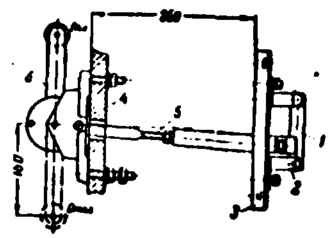

Fig. 15-3

Fig. 15-2. Knife switch is tripolar on 1000 A with central handle.

Fig. 15-3. Knife switch tripolar to 400 A with rigging. 1 - knife; 2 - the fixed contacts; 3 - insulating plate/slab; 4 - metal panelboard; 5 - rod; 6 - control lever.

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Automata fulfill the functions of two simplest apparatuses - knife switches and safety fuses and provide more reliable cutoff/disconnection and selective overcurrent protection. Is explained this by the more stable shielding characteristics of the automata (see further) in comparison with the characteristics of safety fuses and the possibility of the more fine adjustment of the specific current of the cutoff/disconnection of automaton. Very important is the recurrence of the action of automata, which

simplifies the operation of installation.

Automata are intended for comparatively rare inclusions and cutoffs/disconnections of circuits. If necessary for frequent process/operations should be applied contactors and magnetic starters (see § 15-3 and 15-4).

In the diagram of Fig. 3-2 automata of maximum current T > are shown on the side of 380/220 V transformers T-1 and T-2 and on two waste/exiting lines 380/220 V.

Fig. 15-4 gives the schematic diagram a and the schematic outline b of the simplest single-pole automaton of maximum current without time element. In the connected position the automaton is held by trip 4, engaged with the lever of 3 handles 10. Spring 7 provides the reliability of this cohesion/coupling.

Magnet coil 9 is connected in series into circuit and through it flows/occurs/lasts the current of load. The armature 6 of trip 4 approaches to be pulled magnet core, but to this blocks spring 7. When circuital current exceeds certain rating value, armature 6 is attracted/tightened to magnet core 9, trip 4 is turned on axis 5 and frees/releases lever 3, after which under the action of disconnecting spring 2 and dead weight the knife of 1 automata is disconnected. The

position of trip with off automaton is determined by backstop 8.

Electromagnet 9, which directly affects the trip of automaton, is simplest electromagnetic primary relay of the maximum current of direct action, which in automata is accepted to call trip of maximum current or simply maximum release.

The spill current of maximum release is called the minimum value of the current with which the release operates/wears and automaton is disconnected. The spill current of maximum release $I_{c.p}$ depends on the tension of control spring 7: with an increase in the spring tension the value of the spill current of maximum release increases and vice versa.

The time of action of automaton is determined in essence by the inertia of its moving elements and by the duration of arc extinction, which appears with the cutoff/disconnection between the contacts of switch. Usually the tripping time of circuit by similar automata is 0.05-0.25 s.

Fig. 15-4c gives the shielding characteristic of the dismantled automaton, i.e., the dependence of the time of its functioning on current in the magnet coil 9t=f(I), from which it is evident that at all values of the current of circuit $I<I_{c.p}$ the automaton remains

connected, and with $I > I_{c.p}$ it disconnects circuit for time $t_{отк}$, the latter not depending on current kV of circuit. This characteristic is called independent variable.

So that the automaton without time element would not be disconnected with the short-term overloadings, not dangerous for electrical equipment, for example under the action of the starting currents of electric motors, is established/installed similar $I_{c.p}$, so that the maximum release would not operate/wear and automaton was not disconnected with the short-term current spikes of load indicated.

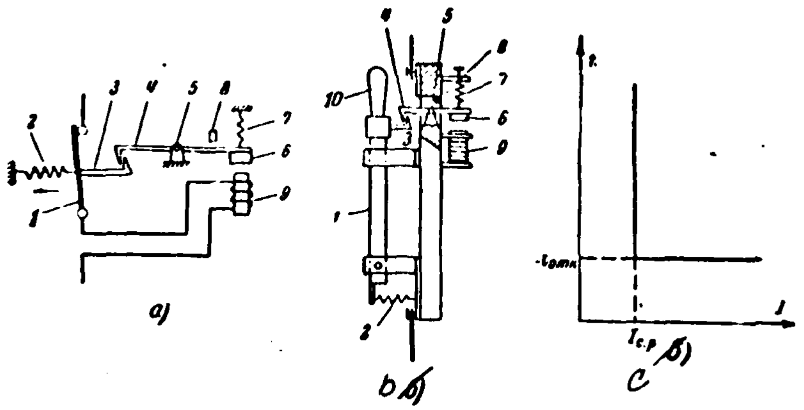

Fig. 15-4. Single-pole automaton of maximum current without time element. a) the schematic diagram; b) the outline; c) shielding characteristic.

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However, in this case the protection of installation is coarsened, since automaton no longer shields electrical equipment from all overloadings less $I_{c.p}$ (Fig. 15-4c). With large value $I_{c.p}$ the automaton virtually shields setting only from short-circuit currents.

The majorities of automata have maximum releases without time element (momentary effect). Some automata can be supplied with maximum releases with the clockwork, which ensures adjustable time element of functioning with the overloadings; during short circuits

this release operates/wears without time element. If necessary some of these automata additionally can be supplied with the electromagnetic retarders, which ensure specific time element with the cutoff/disconnection of short-circuit currents.

If with established/installed time element the tripping time $t_{отк}$ of automaton is more than the duration of the short-term current spike of load, then current $I_{c.p}$ can be reduced. This leads to sensitization of protection (in more detail than cm Vol. 2, chapter 13).

An essential deficiency/lack in the automaton, given in Fig. 15-4, is the absence of the mechanism of the free release, which ensures automatic cutoff/disconnection of automaton during short circuit in circuit and when for any reason its handle 10 is prolongedly held by hand in the connected position.

Actually/really, if this automaton is established/installed, for example, on the waste/exiting line of panel 280/220 V (Fig. 3-2), then in the case of its inclusion to the existing in network short circuit it will not be able to be disconnected, until its handle is held by hand. As a result of this will be disconnected the automata T> on the side of 380/220 V transformers T-1 and T-2 completely will be discontinued the feed of collecting mains by 380/220 V.

Thus, automata without the mechanisms of free release are insufficiently reliable and they do not usually provide the selective protective system of installation. They are undesirable also from safety conditions of maintenance/servicing, since with their cutoff/disconnection is moved control handle, which can cause strong injuries to a person, located before the automaton.

Fig. 15-5 in the form of an example shows the mechanism of the free release of automaton, made in the form of the system of breaking levers 6. At the connected position of automaton center 9 lies/rests somewhat lower than straight line, which connects hinges 7 and 8, and it cannot be dropped/omitted still below, so that upon the start of automaton linkage 6 is rigid. If the shock worker of the core 5 of disconnecting coil 4 turns the components/links of lever 6 so that hinge 9 will prove to be above straight/direct, which connects hinges 7 and 8, then contacts 2 and 3 switches are radiated without depending on the position of handle 1 (Fig. 15-5b). In order to again include/connect switch, it is necessary to supply handle in the position, which corresponds to off switch (Fig. 15-5c), then center 9 again proves to be below straight/direct 7-8 and automaton can be connected.

Usually the mechanism of free release is performed so that with manual cutoff/disconnection the rotation of handle (from position in Fig. 15-5a) causes the fracture of linkage 6 after which the contacts of automaton rapidly they diverge under the action of the disconnecting springs. Further rotation of handle to the side of cutoff/disconnection is necessary for the preparation of automaton for the subsequent inclusion. Therefore the rate of the disagreement of contacts, but thereby the rate of arc extinction, which appears on the contacts of automaton with the cutoff/disconnection of considerable currents, does not depend on that rate with which the man moves control handle.

The contact system of automata normally consists of working and arcing contacts. The first usually perform in the form of massive copper bands to which in places their contacts frequently weld on silver plates. Earlier as the make contacts of automata were used extensively the brush contacts; at present brush contacts go out of use.

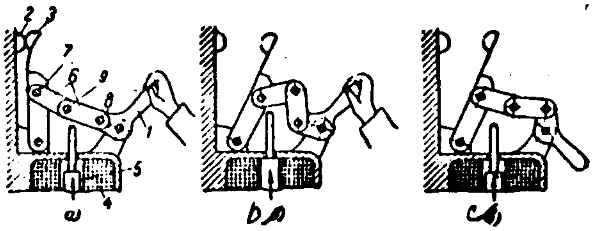

Fig. 15-5. Principle of the device/equipment of the mechanism of the free release of automaton. a) automaton is connected; b) after the automatic cutoff/disconnection of the automaton; c) automaton is prepared to inclusion.

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The arcing contacts of automata have detachable carbon or brass caps; they recently apply also caps of the cermet connections on the base of silver (chapter 12). Automata to large operating currents frequently have also preliminary contacts, employees for the protection of make contacts from the action of arc in the case of damaging the arcing contacts. With the cutoff/disconnection of such automata are first broken the make contacts, then preliminary and by the latter arc-suppression; they are included contacts in reverse order.

Automata to the small working and disconnected currents can have one pair of the contacts, which perform the role of workers and

arc-suppression.

For accelerating the extinction of an electric arc and increase in the disconnecting ability with the cutoff/disconnection of short-circuit currents the automata are supplied with arc-suppression gratings with metallic plates or with plates from non-arcing insulation (chapter 13). With the cutoff/disconnection of current in the limits of that permitted the arc does not exceed the limits of arc-suppression grating, which makes it possible to very compact establish/install automata in the distributing frames of low voltage.

In installations of direct current are applied one- and two-pole automata with one or two maximum releases. In three-phase three-wire installations are applied tripolar automata with two or three maximum releases, while in four-wire installations 380/220 V and 220/127 V, where are possible single-phase short circuits, tripolar automata only with three maximum releases.

— Besides maximum releases some automata can be equipped with one supplementary release; independent variable (disconnecting) or minimum (zero).

In the presence in automaton of several releases each of them, independent of others, it operates on the mechanism of the free

release of automaton.

Fig. 15-6 gives the schematic diagram of tripolar automaton with two maximum ones and one independent (disconnecting) release. The latter is connected to busbars of control ShU of the auxiliary source of the direct current through the normally extended knob/button O and blocking contacts 8 (blocking contacts), locked with the connected automaton.

The magnet coils of 1 maximum releases are connected in series during the phases of circuit. When current at least in the coil of one release increases to the value of its spill current ($I \geq I_{c.p}$), the armature of 2 corresponding releases will be pulled to magnet core, overcoming the force of spring 4, and striker 3 will act on general/common/total for all poles cylinder of cutoff/disconnection which in turn, will free the mechanism of free release, and automaton will be disconnected. In the diagram for the purpose of simplification instead of the cylinder of cutoff/disconnection and mechanism of free release is shown general/common/total trip 6, on which operate shock workers 3 all releases of automaton. Dotted line showed that each maximum release can be supplied with the mechanism of time element 5.

The independent or disconnecting release is arranged

analogously. Normally the about coil of its electromagnet 7 current does not flow. For the remote (at a distance) cutoff/disconnection of automaton serves the knob/button of cutoff/disconnection O with the aid of which close circuit the magnet coils 7. During the subsequent release of knob/button O, which has return spring, it current does not disrupt, since the circuit of electromagnet 7 proves to be preliminarily extended blocking contacts 8. This is necessary in order to warn/prevent the burning of the contacts of knob/button O with the break of circuit of electromagnet. Blocking contacts more powerful/thick and less suffer with the disruption of this circuit.

Blocking contacts consist of two motionless ones and one slide contacts. The latter is mechanically connected with the movable system of automaton, usually with its shaft. The device/equipment of the simplest blocking contacts can be seen in Fig. 15-14, where contacts 17 are locked, and contacts 18 are extended with off switch. Upon the start of switch contacts 17 are broken, and contacts 18 are closed.

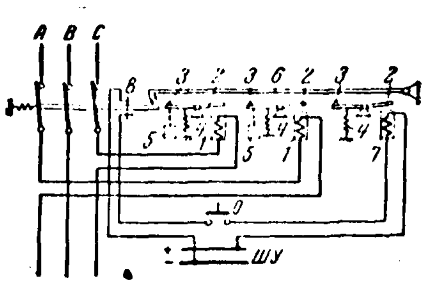

Fig. 15-6. Schematic diagram of tripolar automaton with the independent release.

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Automata can be supplied with several pairs of blocking contacts for different purposes (Fig. 15-6, 15-7, 15-8).

The independent release can be utilized for the cutoff/disconnection of automaton with the aid of any separately established/installed relay with the closing contacts.

In the form of an example let us examine the schematic of bipolar automaton with separate reverse-current relay (Fig. 15-7). Such automata are installed in the circuits of direct-current generators, which work in parallel with other generators or with storage batteries. Their designation/purpose - to shut off generator with an excessive increase in the current, for which serves maximum

release 1, and with change the directions of direct current, for which serve as reverse-current relay 3, which closes the circuit of the electromagnet of independent release 2.

If on any reasons (reduction in current of excitation, speed of rotation, etc.) decreases emf of one of the in parallel working generators, then it throw off and at the value of emf smaller than the voltage on the busbars of installation, begins to work by electric motor - direction of flow in circuit changes to reverse (with the constant/invariable polarity of network). The work of generator in the mode/conditions of electric motor leads to the unproductive charging of other working of network generators. If generator worked together with storage battery, then its transition/junction into engine operating mode leads to the unproductive discharge of storage battery. Reverse-current relay, which operates/wears with a change of direction of flow in the circuit of generator, and serves in order not to allow the work of generator in engine operating mode.

Reverse-current relay 3 has two coils - consecutive 4 and parallel 5. The latter is designed for the voltage smaller than the line voltage; therefore it is connected through supplementary resistor/resistance to 7.

In normal direction of flow in the primary circuit of generator the magnetic fluxes of the coils of relay 3 are directed contrarily, the resulting magnetic flux is small and the core of relay cannot be sucked inside coils - contacts 6 remain by those extended. In the case of changing direction of flow in the circuit of generator with the constant/invariable polarity of the poles of network changes direction of flow only in consecutive coil 4, and direction of flow in parallel coil 5 remains constant/invariable.

In this case magnetic fluxes of both coils of relay store/add up, core is pulled and contacts 6 are closed. The latter close the circuit of independent release 2, which disconnects automaton. Blocking contacts 8 break the circuits of coils 2 and 5. After the cutoff/disconnection of the automaton of relay 3 it returns to initial position and its contacts 6 they are broken.

With the idling of the generator of relay 3 it does not operate/wear and automaton remains connected, as the magnetic flux of one parallel coil 5 of relay is insufficient for the retraction of its core.

The schematic of automaton with supplementary minimum (zero) release is given in Fig. 15-8. Maximum releases 1 do not differ from those dismantled/selected above. Minimum release consists of

electromagnet 2 and double-arm lever with armature 3, striker 4 and spring 5. Magnet coil through the knob/button and blocking contacts 6 is connected to line voltage. With the decrease of line voltage of up to certain fixture the force of spring 5 becomes more than the attracting force of armature 3 to magnet core. Under spring effect the lever is turned and striker 4 acts on the release gear of automaton, after which the last is disconnected. Simultaneously the circuit of magnet coil is disrupted by blocking contacts 6.

Minimum releases operate/wear upon disappearance or with a decrease in the voltage on electromagnet to 40o/o of nominal.

Knob/button with normally closed contacts serves for the remote cutoff/disconnection of automaton - with pushing of this knob is disrupted the circuit of the electromagnet of release and automaton.

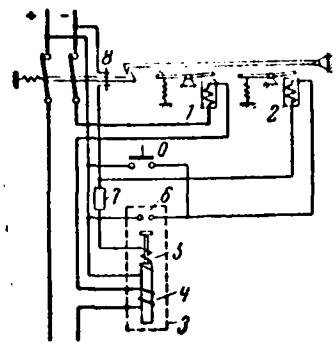

Fig. 15-7

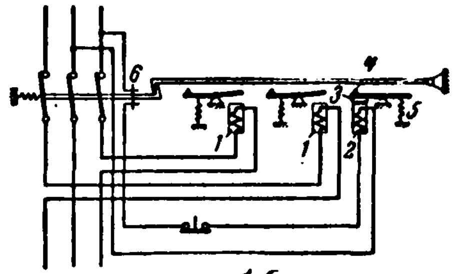

Fig. 15-8.

Fig. 15-7. Schematic diagram of two-pole automaton with the independent release and separate reverse-current relay.

Fig. 15-8. Schematic diagram of tripolar automaton with minimum (zero) release.

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Automata with minimum releases install in electric motors for the purpose of their cutoff/disconnection from network upon considerable decrease or complete disappearance of voltage in power line.

For electric motors with resistance starting this is necessary for the purpose of warning/prevention of automatic starting without rheostats (with the brought-out and shortened/shorted out rheostats), since with resumption of voltage in network it is possible that the

electric motors cannot be swept and they will be damaged as a result of the prolonged course of high currents. The setting up of such automata is necessary also in the cases (even with short-circuited induction motors), when launching/starting engine to total voltage and, therefore, the sudden launching/starting of operating mechanisms inadmissible according to safety conditions for the service personnel. They are necessary also for warning/preventing the simultaneous launching/starting with resumption of voltage in the network of a large number of stopping electric motors, since this can lead to the exaggerated total starting current (for greater detail, see Vol. 2, gl. 6).

Automata are intended for installation on the front/leading or back of the distributing frames. In the latter case they have lever drives for control from the front of panel.

Until recently in the Soviet electrical devices of direct current by voltage to 440 V and of alternating current 50 Hz with voltage to 500 V inclusively great use/application had the automata of series A2000 to rated currents to 1500 A. Fig. 15-9 shows the general view of the tripolar automaton of this series on 200 A and 500 V with two maximum ones and one minimum ones (zero) releases, equipped with arc-suppression gratings 3 with metallic plates (Fig. 13-12). With voltage 500 V limiting current of the

cutoff/disconnection (amplitude value) of these automata is 20-30 kA.

Automata of the type A2050 to rated current 1500 A if necessary have electromagnetic actuator for remote switching.

Ulyanov electrical equipment plant reworked the construction/design of the automata of series A2000 and at present manufacture the modernized automata of series A15, A20 and A25 on currents 100 -1800 A and voltages 380 V of alternating current and 440 V of direct current. The disconnecting ability of these switches is increased to 60 kA (amplitude value) with alternating current and to 30 kA with direct current.

The automata of new series are more reliable, have smaller weight and overall sizes, are equipped with mechanisms time elements, which provides the selectivity of their cutoff/disconnection during overloadings and short circuits. Some of them have drive for remote switching.

Fig. 15-10 shows general view of one of the automata of this series - a tripolar automaton of the type A15 to rated current 600 A.

The powerful/thick automata of series AC to rated currents to 1.5-2.5 kA and more are manufactured by plant "Elektrosila". It is

interesting to note that are recently at plant designed even more powerful/thick automata with cooling of contacts and current-conducting busbars by the distilled or chemically purified water.

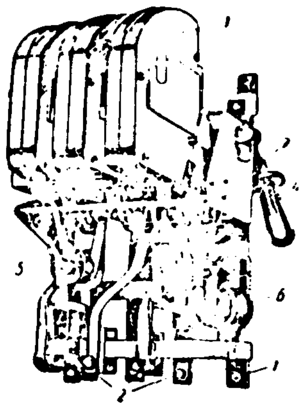

Fig. 15 9

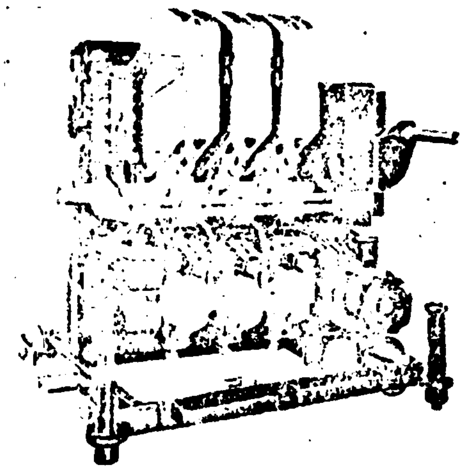

Fig. 15-10

Fig. 15-9. Tripolar automaton of the type A-2000 on 200 A, 500 V. 1 - steel framework/body; 2 - terminals/grippers for the connection of busbars (wires); 3 - chamber/camera of the arc-suppression gratings; 4 - handle; 5 - maximum release; 6 - minimum (zero) release; 7 - case of the mechanism of free release.

Fig. 15-10. Tripolar automaton of type A15 on 600 A, 380 V.

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It proves to be that the water cooling only of fixed contacts makes it possible to increase the rated current of automaton four times. With water cooling can be created the automata to operating currents into several ten thousands of amperes [L. 14-2 and 15-2].

In the installations of alternating current with voltage to 500 V and of direct current to 220 V are inclusively widely applied also the manufactured with Soviet plants adjusting automata of series A3100 to rated currents 50-600 A into one- two- and tripolar performance.

Representation about these automata gives the given in Fig. 15-11 cross section of an adjusting automaton of the type A3120 to current 100 A.

Automata have plastic foundations 1, which makes it possible to install them in metal constructions. Plastic covers/caps 2 provide the safety of their maintenance/servicing.

In cover/cap there is a groove for the handle of 10 manual controls. With lever/crank and electromagnetic actuators these automata are not supplied.

Fig. 15-11 automaton shows in position after automatic disconnection under the action of release. For the start of automaton it is necessary handle 10 to turn downward (10" - the position of handle after manual cutoff/disconnection). In this position the lower

finger/pin of the lever of free release by 12 is seized by trip 13, and idler levers of the mechanism of free release 11 prove tc be prepared to start.

Is connected automaton by the rotation of handle 10 upward, in position 10'. Lever 12 is held in lower position by trip 13. For the automatic cutoff/disconnection of automaton it is necessary to derive lever 12 of the engagement with trip 13. Is reached this via the rotation of trip to small angle to the right. Freed lever 12 is turned it counterclockwise and breaks the hinged connected linkage of the mechanism of free release by 11. Automaton is disconnected (position in Fig. 15-11). The displacement of trip 13 indicated with automatic cutoff/disconnection is realized by releases of automaton.

The given in Fig. 15-11 automaton has the combined releases each of which consists of electromagnetic and thermal elements/cells. Electromagnetic element/cell consists of electromagnet 15 whose coil is connected in series into the busbar of 4 phases (pole) of circuit. Upon reaching by the current of value $I_{c.p}$ armature 16 is attracted/tightened to magnet core 15 and turns the lever of release 18. The latter by means of rack 14 turns the cylinder on which is attached trip 13, after which the automatic device is disconnected. Tripping time during functioning of electromagnetic release is very small - approximately/exemplarily 0.012-0.020 s. The electromagnetic elements/cells of releases realize protection only from short circuits.

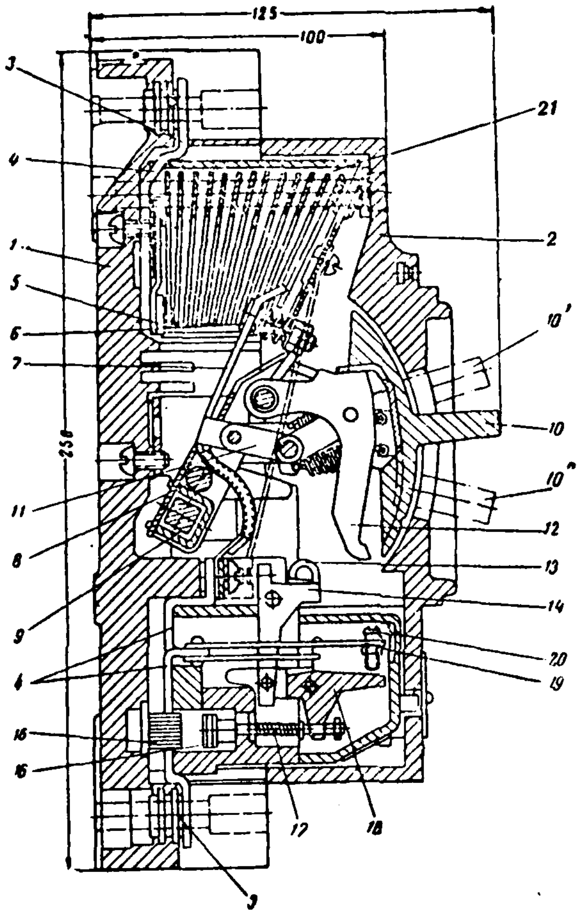

Fig. 15-11. Automaton of the type A3120 on 100 A, 500 V (cross section).

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Overload protection of circuit is realized by thermal element/cell

19, which consists of two connected with each other plates from the different alloys (for example, one plate of nickel alloy with iron, and the second of the constantan), which possess different coefficients of linear expansion during heating (the bimetallic strip). The plates indicated are connected in series into the circuit of the phase of circuit (into the crosscut of busbar 4). In current the overloadings of plate strongly are heated and as a result of different linear expansion are bent so that adjusting screw 20 depress leveres 18 and turns it, that, as noted above, it leads to the displacement of trip 13 and the cutoff/disconnection of automaton. In such a manner both the electromagnetic, and thermal elements/cells of release act on the mechanism of the free release of automaton with the aid of general/common/total intermediate components/links 14 and 18. The time of action of thermal element/cell depends on the current: with an increase in the current of overloading triggering time of thermal element/cell decreases.

Fig. 15-12 shows the characteristic of the combined release. If circuital current is less $I_{н}$, then automaton remains connected. With circuital current from $I_{н}$ to $I_{с.р}$, i.e. with the overloading of circuit, operates/wears the thermal element/cell of release on the dependent part of the characteristic. Currents are more $I_{с.р}$ (virtually short-circuit currents) activate of the electromagnetic element/cell of release and cutoff/disconnection in the course of

time $t_{отк}$, by that not depending on current (independent part of the characteristic).

Adjusting automata with one electromagnetic element/cell of release shield installation only from the currents of short circuiting.

Spring 17 (Fig. 15-11) serves for the return of the mechanism of release to initial position.

Motionless 5 and movable 6 contacts of automaton are made from cermet connections on the base of silver. Slide contact is fastened/strengthened to copper plate 7, connected by flex conductor 8 with busbar 4. Steel isolated/insulated shaft 9 is general/common/total for all poles of automaton.

Automata perform with the front/leading (terminal/gripper 3 on Fig. 15-11) or rear connection of wires (busbars).

Adjusting automata have small overall sizes with the comparatively large disconnecting ability which it is provided by arc-suppression grids 21 with steel plates. Depending on nominal voltage and current adjusting automata are capable of disconnecting short-circuit currents to 40-50 kA [L 14-1].

Besides those indicated above, Soviet plants manufacture small/miniature automata to rated currents to 25 A and voltages to 380 V, supplied with releases with thermal and electromagnetic elements/cells.

15-3. Contactors.

Contactors serve for and automatic remote control of the electric motors or any other circuits in the installations of direct and alternating current as voltage to 1000 V. In contrast to automata contactors do not shield electrical circuits from abnormal modes/conditions (short circuits, overloadings, etc.) and they can be used for frequent starts and cutoffs/disconnections of circuits.

Fig. 15-13 explains the principle of device/equipment and the circuit diagram of single-pole contactor.

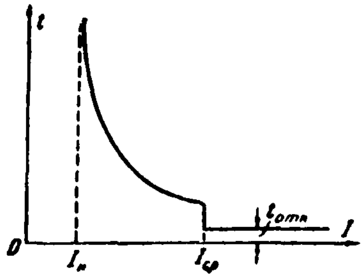

Fig. 15-12.

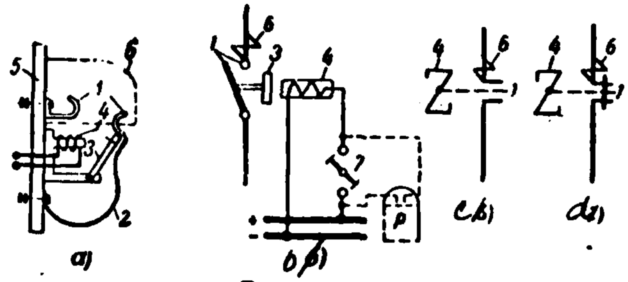

Fig. 15-13

Fig. 15-12. Characteristic of the combined release of an automaton of the type A3000.

Fig. 15-13. Single-pole contactor. a) the schematic of the device/equipment; b) circuit diagram; c) the conditional image of contactor in unilinear diagrams in position is disconnected; d) the same, but in engage position (zigzag 6 above contacts indicates that the contactor is made with arc extinguishing, i.e., is equipped with any arc-suppression device/equipment).

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During closing/shorting by key/wrench 7 (without self-reset) the circuit of the coil of holding magnet 4 armature 3 is attracted/tightened to its core and contacts 1 are closed. For the retention of contactor in the connected position the magnet coil 4 always must flow itself by current, for which key/wrench 7 must be always they will lock, since the contactors of the normally holding

trips do not have. For the cutoff/disconnection of contactor it suffices to disconnect the key/wrench of control of 7. Holding magnet will be de-energized, and contactor will be disconnected under its own weight of moving elements. Some contactors have the disconnecting springs.

Contactors are usually supplied with arc-suppression gratings 6 with metallic plates or with plates from non-arcing insulation.

With the aid of the separately established/installed relays it is possible to realize automatic breaking and cutoff/disconnection of contactors. So, if we connect the normally open contacts of relay R in parallel to key/wrench 7 (broken connections in Fig. 15-13), then during the closing of contacts of relay contactor will be connected and vice versa. Thus, with the aid of contactors and different types of the relays, connected on special diagrams, it is possible to realize automatic control of installation.

Are manufactured also contactors with normally closed contacts (with the de-energized coil of holding magnet). After the excitation by the current of holding magnet these contactors are disconnected. Are applied them in different diagrams of automatic control.

The holding magnet of contactor can be supplied from an external from storage

Current source (Fig. 15-13) for example,
battery, or from the same circuit, into which is connected the contactor. In the second case (Fig. 15-15) with the lowered/reduced line voltage the attracting force of armature to magnet core decreases, and contact can be disconnected. If this according to the condition of the mode of operation of circuit is inadmissible, then it is necessary to supply holding magnet from the independent current source.

In Fig. 15-14 it is given general view and cross sections along the magnetic and contact systems of the tripolar contactor of alternating current of the type KT with arc-suppression gratings.

15-4. Magnetic starters.

Magnetic starters are applied for remote control of asynchronous squirrel-cages motor, included to full/total/complete line voltage.

Magnetic starter consists of tripolar contactor, two thermal relay and blocking contacts, built in the general/common/total cabinet (Fig. 15-15 and 15-16). Control of starters usually pushbutton. In diagram in Fig. 15-15 in contrast to diagram in Fig. 15-13 is provided the feed of holding magnet by 1 by alternating current from the network, which feeds electric motor D.

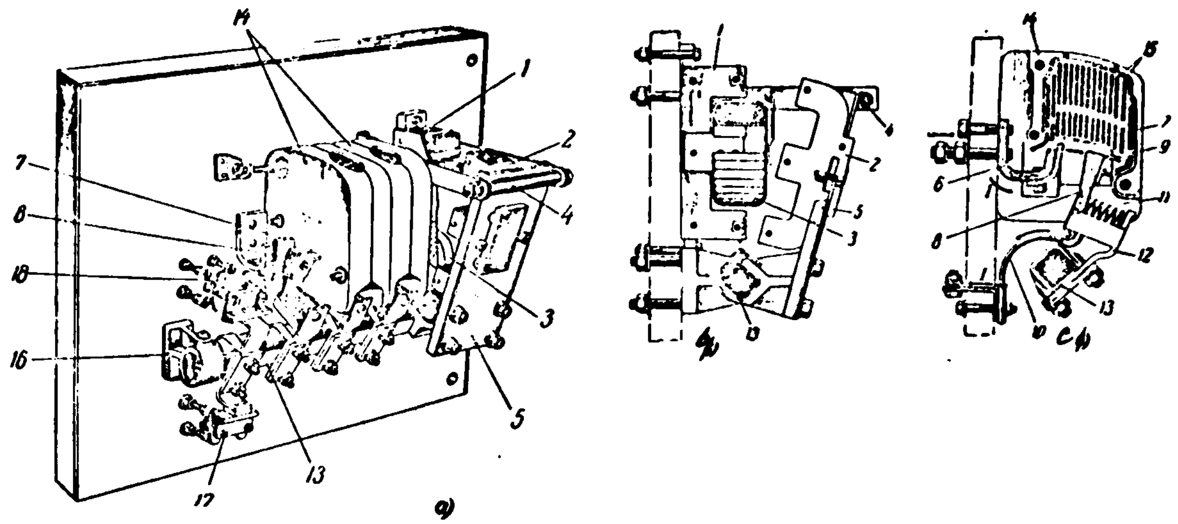

Fig. 15-14. The contactor of alternating current is tripolar with arc-suppression gratings. a) the general view; b) section/cut on the holding magnet; c) section/cut on contacts and arc-suppression grating. 1 - framework with the core; 2 - armature; 3 - the holding magnet; 4 - backstop; 5 - holder of the armature; 6 - contact strut; 7 - motionless main contact; 8 - movable main contact; 9 - arc-suppression horn; 10 - flexible member; 11 - spring; 12 - holder of the slide contact; 13 - shaft from insulation; 14 - arc-suppression grating; 15 - steel plates; 16 - bearing; 17 - breaking blocking contacts; 18 - closing blocking contacts.

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For control of magnetic starter are provided switching on V and disconnecting against the knobs/buttons (the second is normally locked), that also blocking contacts 3, connected with the moving element of the starter.

By pushing of the switching on knob they close the circuit of holding magnet 1 (contacts 5 and 5' thermal relays are normally locked), which attracts/tightens armature 2 and is switched on contactor. Upon the start of contactor are closed blocking contacts 3, which shunt switching on button. After interrupting this knob/button the circuit of electromagnet remains locked through contacts 3, disconnecting knob/button and contacts 5 and 5' thermal relays. Remotely contactor disconnects by pressure the disconnecting knob/button, which disrupts the circuit of holding magnet.

Overload protection is realized with the aid of the thermal relays, built in the starter. Each thermal relay contains composite element/cell 6 (or 6') heated by Nichrome heating element/cell 4 (or 4'), over which flows/occurs/lasts the current of electric motor (Fig. 15-15). About the device of composite elements/cells was said in § 15-2. During interrupting of the contacts at least of one thermal relay (5 or 5') is disrupted the circuit of holding magnet and starter is disconnected.

Magnetic starter disconnects engine also with decrease in the conducted/supplied voltage to 50-60o/o from nominal, since with this voltage holding magnet no longer in state to hold down/retain starter in the connected position.

Magnetic starters do not shield circuit from short circuits; therefore in the circuits of electric motors additionally are installed safety fuses.

The holding magnets of the magnetic starters normally are intended for work only on alternating current. On those engines which after resumption of voltage in power line must be turned/run up automatically (for example the engines of the critical mechanisms of their own needs of power plants), magnetic starters must not have blocking contacts 3 and for control by them must be used the rotary keys/wrenches of control without self-reset as in the diagram of Fig. 15-13.

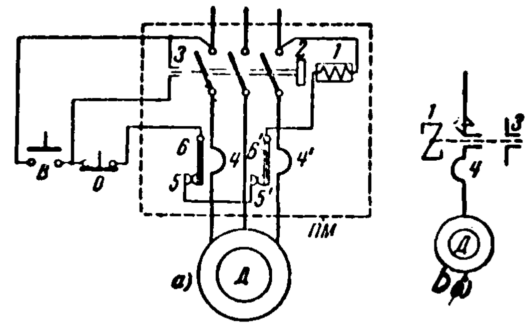

Fig. 15-15

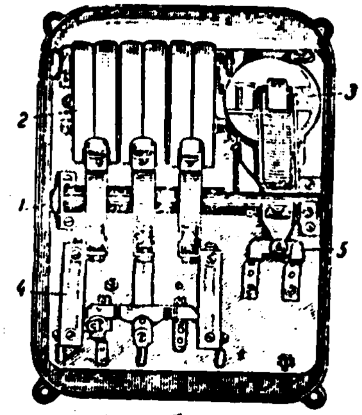

Fig. 15-16.

Fig. 15-15. Magnetic starter. a) the schematic diagram of the device/equipment; b) the conventional designations in unilinear diagrams.

Fig. 15-16. Tripolar starter (cover/cap is taken/removed). 1 - shaft of the contactor; 2 - chamber/camera of the arc-suppression gratings; 3 - the holding magnet; 4 - the thermal relay; 5 - blocking contacts.

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Chapter sixteen .

Disconnectors and drives by them.

16-1. Designation/purpose and types of disconnectors.

By the fundamental designation/purpose of disconnectors is providing safety of production in repair work in electrical devices the voltage of above 1000 V. Disconnectors make it possible to reliably detach (to insulate) those parts of the installations on which must be conducted repair work, from its other parts, which remain under voltage. Because of disconnectors it is possible to ensure the safety of the repair of electrical equipment without the disturbance of other parts of the installation.

The contacts of disconnector are located in air, which provides the visibility of the place of chain cleavage (Fig. 16-1). Distance A between the dead contacts of disconnector must be that so that for its breakdown would be required voltage larger than for the breakdown of distance B between the phase and the grounded by part construction/design of disconnector or between its phases. By this is

prevented the possibility of the overlap between the dead contacts of disconnector with the onset of overvoltages in installation.

Disconnectors do not have arc-suppression devices/equipment; therefore by them it is not possible to disconnect the currents of the loads, with which on their contacts is formed powerful/thick electric arc. This open arc not only can destroy disconnector and near to it electrical equipment, but it can overlap phases and cause short circuit in installation. Open arc is very dangerous for the service personnel. Therefore disconnectors normally are utilized for start and stop of the de-energized parts of the installation, preliminarily off by switch.

In some diagrams of the electrical connections of stations and substations are utilized the disconnectors also for switchings, if they are not accompanied by the onset of arc on the contacts of disconnector, for example, them are utilized for switching of circuits from one system of collecting mains to another (see § 3-2, Fig. 3-4).

The at the same time many-year experience of operation established/installed, which by disconnectors is possible to successfully switch on and to disconnect circuits with the small currents when on the contacts of disconnector arc in no way appears

or appears a comparatively weak arc, easily extinguishing in the open air without the danger of the decomposition of disconnector or overlap of its phases. This use of disconnectors for the cutoff/disconnection of circuits with small currents frequently makes it possible to refuse from the use/application of expensive and bulky high-voltage switches and substantial to simplify and to reduce the cost of the distributor of the installation (see also Vol. 2, chapter 2-5). With respect to the aforesaid by disconnectors it is possible to switch on and to disconnect [L. 3-6 and 16-1]:

1) charging rate of collecting mains and electrical equipment, air electric power lines by voltage to 20 kV of inclusively any length, air electric power lines by voltage 35 kV in long to 30 km and 110 kV - to 20 km, cable lines with voltage up to 10 kV in long to 10 km;

2) the running-light current of power transformers with a power of:

with voltage to 10 kV inclusively ... of 750 kVA.

with voltage 20 kV ... of 3200 kVA.

with the voltage 35 kV ... of 20,000 kVA.

with the voltage 110 kV ... of 31,500 kVA.

(disconnectors they must be tripolar with the power drive);

3) voltage transformers;

4) the neutral of power transformers and the arc-arresting coils;

5) the cross current of lines when a difference in voltage on disconnector after cutoff/disconnection comprises not more than their 2o/o nominal value;

6) the current of single-phase closing/shorting to the earth: 5 A for lines by voltage 20-35 kV and 10 A - for lines with voltage 10 kV and below.

Is allowed/assumed so cutoff/disconnection by the disconnectors of the current of load up to 15 A with voltage to 10 kV.

Disconnectors must possess a sufficient for conditions this installation electrodynamic and thermal resistance and must be

mechanically durable, maintaining/withstanding without any damages the established/installed by norms number of starts and cutoffs/disconnections.

By a number of poles distinguish disconnectors one- and tripolar; on the kind of installation - for the internal and external installations; using mounting method - with the vertical or horizontal location of knives. By construction/design are distinguished cutting type disconnectors - with the rotation of knives in the plane of axes of the insulators; the rotary type - with the rotation of knives in the plane, perpendicular to the axes of the insulators; plug type - with the insulators, which move with start and cutoff/disconnection along their axis, etc. [L. 16-2].

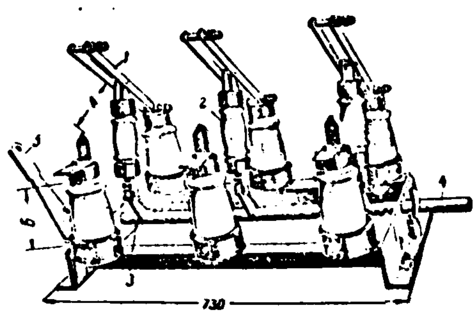

Fig. 16-1. Tripolar disconnector for internal installation on 10 kV, 400 A.

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Besides working knives the disconnectors can still have the grounding knives which are utilized for shorting and grounding of the phases of the parts of the installations during repairs (after their full/total/complete cutoff/disconnection from other parts, which are located under voltage).

Soviet plants manufacture disconnectors for internal and external installation to entire voltages up to 500 kV inclusively (table P-13).

16-2. Disconnectors for internal installations.

For internal installations Soviet plants manufacture cutting type single-pole and tripolar disconnectors, normally adjusted in vertical position. Majorities of them have linear contacts.

General idea about tripolar disconnectors for internal installation to voltages 6-10 kV gives the disconnector, given in Fig. 16-1. Knives 1 rotate with the aid of pivoting porcelain rods 2, hinged connected with the bands of knife 1 and with levers 3 on general/common/total shafting 4.

Control of tripolar disconnectors is usually realized by the special drives (§ 16-4), which with the aid of steel rods connect with drive lever 5 on the shaft of disconnector. Disconnectors to small rated currents (usually not more than 600 A) can be also switched on and disconnected with the aid of operational rod from insulation. At the end/lead of the rod there is finger/pin, which with process/operations from disconnector is introduced into opening/aperture at the end/lead of its rocker shaft arm 5. By rotating the last rod, switch on or disconnect disconnector.

At present Soviet plants manufacture tripolar disconnectors for the internal installation of the single (all-Union) series which appropriated a designation of the type RV. In the disconnectors of this series (Fig. 16-2) are used the improved and more fail-safe

design linear contacts with the magnetic locks which were in detail described in § 12-3 and given in Fig. 12-11, and also small/miniature porcelain insulators with internal reinforcing (chapter 9), which substantially lowered overall sizes and weight of disconnectors in comparison with the previously released disconnectors on insulators with the external attachment or armature, for example types RVT, RLVIII, etc.

The tripolar disconnectors of series RV if necessary can be equipped with the knives of grounding, established/installed from any side of main knives, type RVZ, and also they can be made on three supporting/reference ones and three passage ones or on six wall entrance insulators - type RVF (F - the figure performance of disconnector, i.e., on wall entrance insulators).

The knives of disconnectors to rated currents to 1 kA inclusively consist of two copper bands of rectangular cross section. To high currents the knives of disconnectors to more advantageously perform from several pairs of bands. So, the knives of disconnectors to current 2 kA consist of two pairs of rectangular bands.

In disconnectors to currents 3 kA and more most advantageous is the box form of current-carrying parts, since in this case is reached better use and, consequently, also the savings of copper, and also the high mechanical strength of knives.

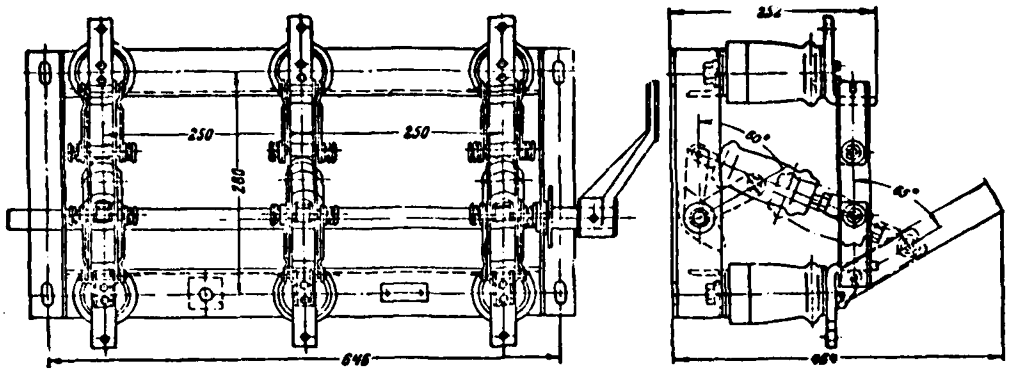

Fig. 16-2. Disconnector tripolar of the type RV 10/400 on 10 kV, 400 A.

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Such knives (Fig. 16-3) are used in heavy-current disconnectors of the type RVK, manufactured with Soviet plants in currents 3 kA and more and voltage 10 and 20 kV. In these disconnectors are used also small/miniature porcelain insulators. As a result of entire this is achieved/reached the considerable decrease of overall sizes and weight of disconnectors in comparison with previously released to the same rated currents disconnectors of types RVO, RO and RLVIII.

The knives of disconnectors of the type RVK to current 3 kA consist of two box busbars, which encompass the motionless contact struts, also made from box busbars (Fig. 16-14), while those of

disconnectors on 4-6 kA - of four box busbars, which in pairs encompass contact struts (Fig. 16-3 and 16-15). Knives are equipped with contact springs and magnetic locks. The current-carrying parts of the disconnectors to currents 3, 4 and 5 kA are assembled on two stand-off insulators, while those of the disconnectors on 20 kV and 6 kA - on four insulators, as is evident in Fig. 16-3, where are used stand-off insulators of the type OME-20.

Disconnectors of the type RVK are manufactured in the form of the separate poles, equipped with shaftings. Tripolar disconnectors compose of three such disconnectors by the connection of their shafts by the rigid couplings (Fig. 16-14). This construction/design makes it possible to install between the axes of the poles of disconnector different distances, which can be caused by the need of guaranteeing the electrodynamic stability of busbar/tire construction/design or by any design features of distributor.

If the distance between centers of busbars and poles of disconnector different, then upon the connection of busbars to disconnector is necessary to somewhat bend them, which is conjugated/combined with considerable difficulties with heavy heavy-current busbars (packet of flat/plane or box busbars). With disconnectors of the type RVK this it is possible to avoid via the selection of the corresponding distance between its poles.

The terminals/grippers of disconnectors of the type RVK make it possible to connect up them busbars both prone and to edge/fin (with respect to the stand-off insulators of disconnector). These disconnectors are manufactured only on stand-off insulators.

Fig. 16-4 in the form of an example gives single-pole disconnector for internal installation of the type RVO (single series). In these disconnectors is used accurately the same contact system, as in tripolar disconnectors of the type RV. Insulators - supporting/reference, small/miniature.

Single-pole disconnectors to currents 400 and 600 A they switch on and disconnect by hand with the aid of operational rod. With the fulfillment of process/operations the finger/pin of rod is introduced into the opening/aperture of lug 1, fastened/strengthened to axis 2 between the plates of 3 knives.

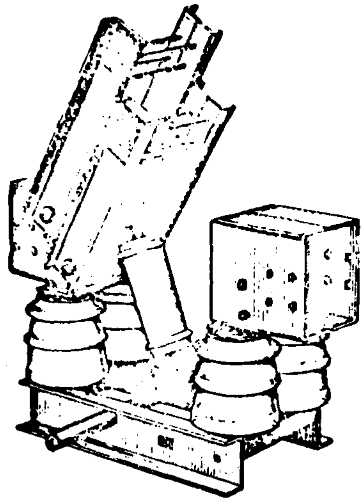

Fig. 16-3

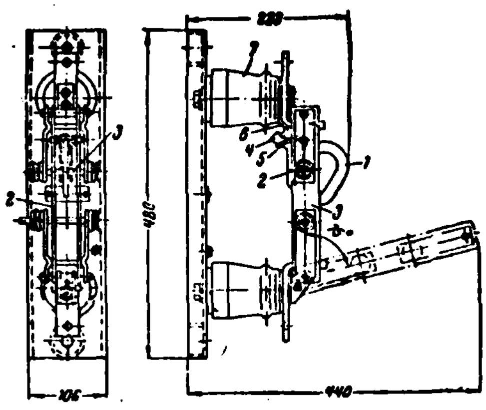

Fig. 16-4

(20 kV and 6000 A)

Fig. 16-3. Disconnector of the type RVK-20/6000 on X (one pole).

Fig. 16-4. Disconnector single-pole of type RVO-10/400 on 10 kV, 400 A.

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Single-pole disconnectors to rated currents 1 and 2 kA have shaftings (as the poles of disconnectors of the type RVK) with established/installed on them rocker shaft arms, with the aid of which they switch on and disconnect disconnectors by rod.

The current, flowing on the current-carrying parts of the disconnector, changes its direction, as this is shown in Fig. 16-5.

As a result of interaction of currents in the elements/cells of the current-carrying outline of disconnector appears certain net force F, applied to knife and trying to disconnect it (to break the loop of current). The greatest value this force reaches with the course of impact short-circuit current. So that in this case the knife of disconnector spontaneously would not be disconnected, since this can be the reason for serious emergency in installation, the frictional force in contact, which depends on the tightening of contact springs and on the force of the mutual attraction of the bands of knife and steel plates of magnetic lock, it must be more than indicated electrodynamic force F. If this condition provide then on the knife of disconnector is provided for the lock (trip), which locks it in the connected position. This lock equipped disconnector in Fig. 16-4.

In the connected position of disconnector the tooth of 4 lugs 1 seizes clamp 6, fastened/strengthened to upper stand-off insulator 7. The reliability of cohesion/coupling provides spring 5, which attempts to turn lug in the direction of rotation of hour hand. With the cutoff/disconnection when the finger/pin of operational rod is introduced into the opening/aperture of lug, the latter is turned in opposite direction, thanks to which tooth 4 and clamp 6 are released and knife 2 is freed/released.

Tripolar disconnectors do not have similar locks, since their

spontaneous cutoff/disconnection is removed with the aid of retaining catches in drives, and also the corresponding positions of the levers of transmission from drive to the shaft of disconnector - a position of levers, close to their "dead" position (Fig. 16-11 and 16-12).

16-3. Disconnectors for external installations.

Disconnectors for external installations must possess the appropriate insulation, calculated for a work under unfavorable environmental conditions (dust, moisture), and also the increased mechanical strength, since process/operations with them are conducted also by the presence of ice-covered surface on contacts. Their contacts as far as possible must be made so as to the layer of ice-covered surface easily it would break also in this case they would not be created the considerable efforts/forces, operating on the fracture of stand-off insulators.

In the open distributors by voltage 35-220 kV are very common cutting type Soviet disconnectors with the rotation of knives in the plane of the insulators of types RLN (disconnector with linear contacts for external installation) and RLNZ (with one or two grounding knives). These disconnectors are manufactured in the form of the separate poles, connected on the spot of installation into one tripolar apparatus.

Fig. 16-6 shows the average/mean pole of a disconnector of the type RLNZ-35. Outer insulators 2 are fixed on frame 1 of angular steel; average/mean insulator 3 is established/installed on bearing and can be turned around its axis. Knife 4 is made from the copper tube whose one end is squeezed in the form of the blade to which is riveted steel cap 8, which is movable horn. Knife throws in itself into fixed contacts 6 and 7, equipped with springs. The busbars of distributor terminate 10 and 11. In the connected position the current flows/occurs/lasts through the following parts: 10-7-4-6-11.

Tubular knife 4 is passed within the plug of crosspiece 12, which can be turned in vertical plane on axes, which are located in bearings 13, base-mounted 14. Together with crosspiece in vertical plane can be turned knife 4.

To tube 4 it is put on and tightly on it jammed cast iron clamp 15, hinged connected with the framework (moving support) 16. The latter encompasses knife and by the second end/lead with the aid of lug and thimble 17 it is connected with leading lever 18, fastened/strengthened to the cap/hood of rotary insulator 3.

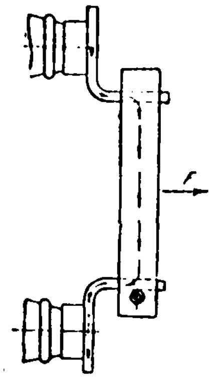

Fig. 16-5. Force, which operates on the knife of disconnector with the course of short-circuit current.

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The levers 19 of rotary insulators of three phases connect with thrusts/rods. The insulator of average/mean phase they connect by vertical shaft 20 with drive. Therefore during the rotation of average/mean insulator simultaneously rotate the insulators of other two phases.

With the cutoff/disconnection of disconnector insulator 3 with the aid of lever 19 is turned clockwise. Together with insulator is turned leading lever 18, from which the motion is transmitted to framework 16. The latter in the beginning of motion turns clamp 15, and together with it and knife 4 around its axis to angle of approximately 80°. During further rotation of insulator framework 16

begins to push clamp 15 upward, as a result of which the knife also starts to agitate itself upward, rotating on the axes of crosspiece 12. In off position 4' knife is held by the trip, available in drive.

Upon the inclusion the knife first rotates in vertical plane and is omitted, in this case its flat/plane end/lead by the narrow side freely enters between the jaws of fixed contact. After accepting horizontal position, knife is turned around its axis to angle of approximately 80° and its flat/plane end/lead wedges the jaw of fixed contact, thanks to which the contacts clean themselves well and is created the necessary pressure in contact.

Because of the combination motion of knife the disconnector works very smoothly and insulators do not test impact and bending loads. Is provided the light fracture of ice and good cleaning/purification of contacts with icing.

In the case of process/operations for arc current appears on horns 8 and 9, which shields from decomposition by arc main contacts of disconnector.

Grounding knife 21, made from steel tube with copper contact cap, is welded to shaft 22 and is connected by flexible copper connection/communication 23 with frame 1, which must be reliable

grounded. The shafts of 22 three poles connect by the cuts of tubes 27.

With process/operations with the grounding knives vertical drive shaft turns the shaft of 25 disconnectors, from which the motion with the aid of levers and thrust/rod by 24 is transmitted to the shaft of the grounding knives. The drive of disconnector is made so that the grounding knives can be included/connected only after the cutoff/disconnection of working knives. The latter in connected position 21' throw in themselves into contacts 26, fastened/strengthened to the caps/hoods of insulators 2.

Each pole of disconnector can have two knives of the groundings, established/installed from the side of both outer insulators 2.

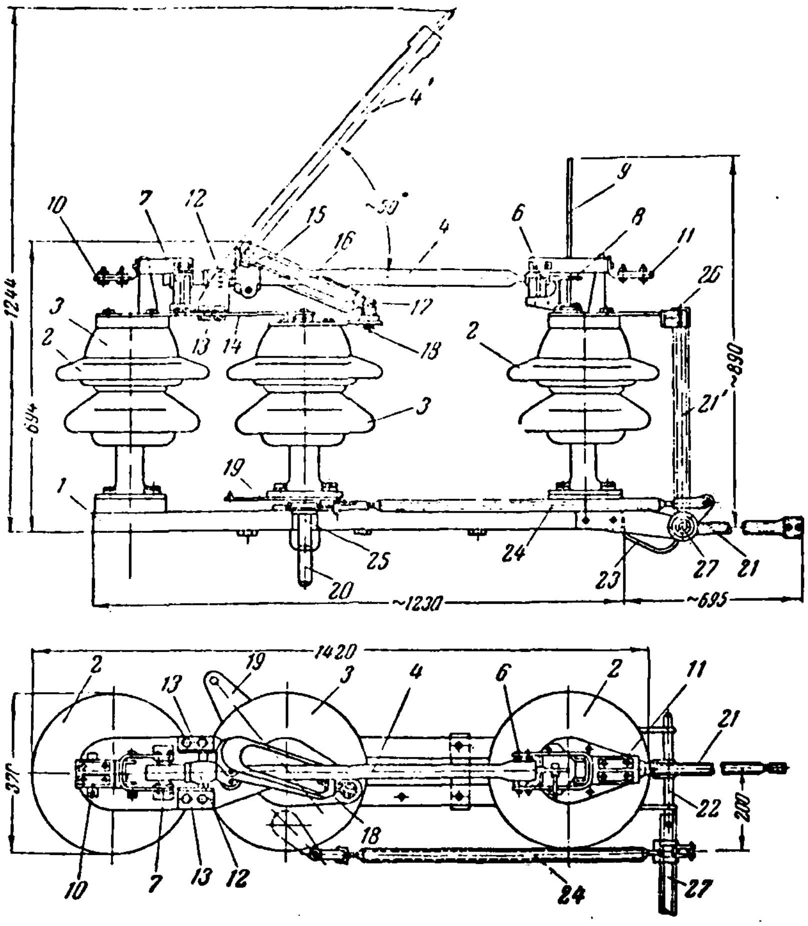

Fig. 16-6. Disconnector of the type RLN3-35 on 35 kV, 600 A with one grounding knife (one pole).

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Disconnectors by voltages 110 kV and higher have analogous construction/design, but they are supplied with columns of several pin insulators. Fig. 16-7 shows the pole of this disconnector of the type RLNZ-220 on 220 kV with grounding knife 1 in the form of folding linked quadrilateral. During the rotation of shaft 2 against the direction of rotation of hour hand knife 1, being straightened/rectified, rises upward and it throws in itself into the contacts of grounding 3; during the rotation of shaft in opposite direction knife 1 stores/adds up and occupies the position, depicted in figure.

Working knife 4 is moved during the rotation of the average/mean column of insulators 5; the mechanism of the motion of knife is similar/such to the examined higher mechanism of disconnector by voltage 35 kV.

Since 1958 the plant "electrical device" manufactures to voltages 10-110 kV the disconnectors of new construction/design - two-core disconnectors with the rotation of knives in the plane,

perpendicular to the axes of insulators. Fig. 16-8 shows the average/mean pole of this disconnector on 110 kV of the type RLND (D - two-core). Disconnector can have one (type RLND1) or two (RLND2) those grounding of knife to pole. In these disconnectors are used rod stand-off insulators 1 and 2 for external installation of the type ST-110. The collars of insulators are connected by thrust/rod 3. With cutoff/disconnection both insulators are turned around their axes to angle of around of 90° in the direction, shown by rifleman/pointers.

Rocker shaft arms of 4 three poles connect by rods, and the shaft 5 of insulator of average/mean pole they connect with vertical drive shaft. Thus, with process/operations with disconnector drive simultaneously turns all insulators of three poles of disconnector.

The slide contacts of disconnector consist of two flat/plane knives 6 and 7, which with cutoff/disconnection are turned in position 6' and 7'. To knife 6 are fastened/strengthened contact commutator bars 8, equipped with flat/plane steel springs. In the connected position knife 7 throws in itself between commutator bars 8. The layer of ice-covered surface on contacts upon inclusions/connections and cutoffs/disconnections easily breaks and insulators do not experience considerable bending stresses.

The busbars of distributor terminate 9 and 10, which by flexible current-carrying connections/communications 11 and 12 are connected with knives 6 and 7.

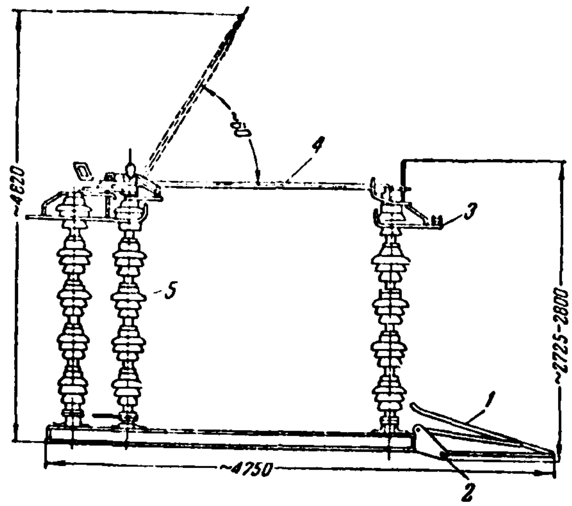

Fig. 16-7. Disconnector of the type RLNZ-220 on 220 kV, 600 and with one grounding knife (one pole).

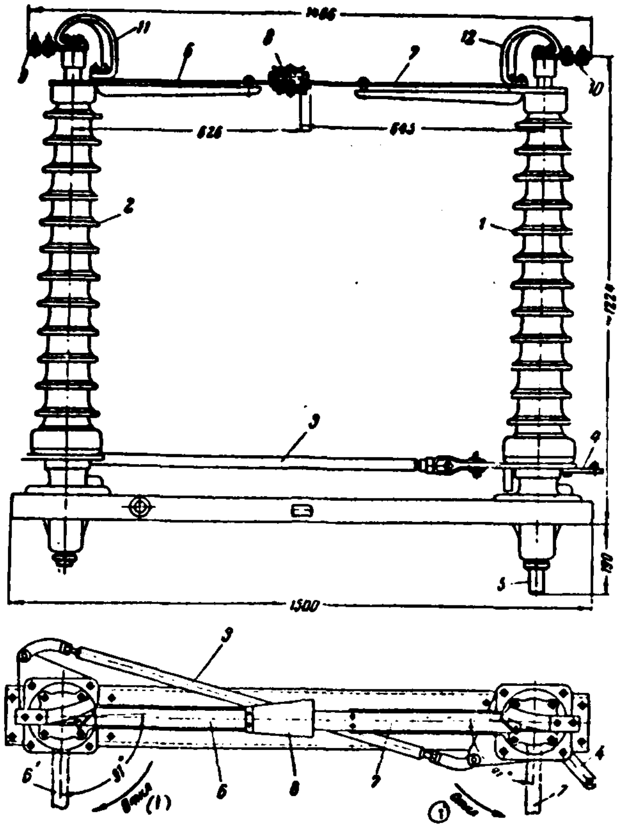

Fig. 16-8. Disconnector two-core of the type RLND-110 on 110 kV, 1000 A (one pole).

Key: (1). Off.

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Two-core disconnectors of the type RLND have simpler construction/design, smaller overall sizes, weight (2.5-3.5 times)

and cost/value in comparison with three-core disconnectors. Because of a smaller number of insulators is above the reliability of their operation.

Fig. 16-9 shows the pole of a disconnector of the type RONZ-400 to voltage 400 kV. As a result of large sizes/dimensions the stand-off insulators are made in the form of trihedral pyramids from columns 1, 2 and 3, comprised of stick insulators. The knife of disconnector 5 long than 5 m is made from tubes. With cutoff/disconnection the knife is turned in vertical plane. In motion the knife is given by electric-motor drive 6 with the aid of the homing/driving column of insulators 4. Disconnector is equipped with folding grounding knife 7.

Plant "electrical device" develops/processes by voltage 500 kV and current 2 kA a two-core disconnector of the type RND-500/2000 whose construction/design in principle the same as the examined above two-core disconnector on 110 kV.

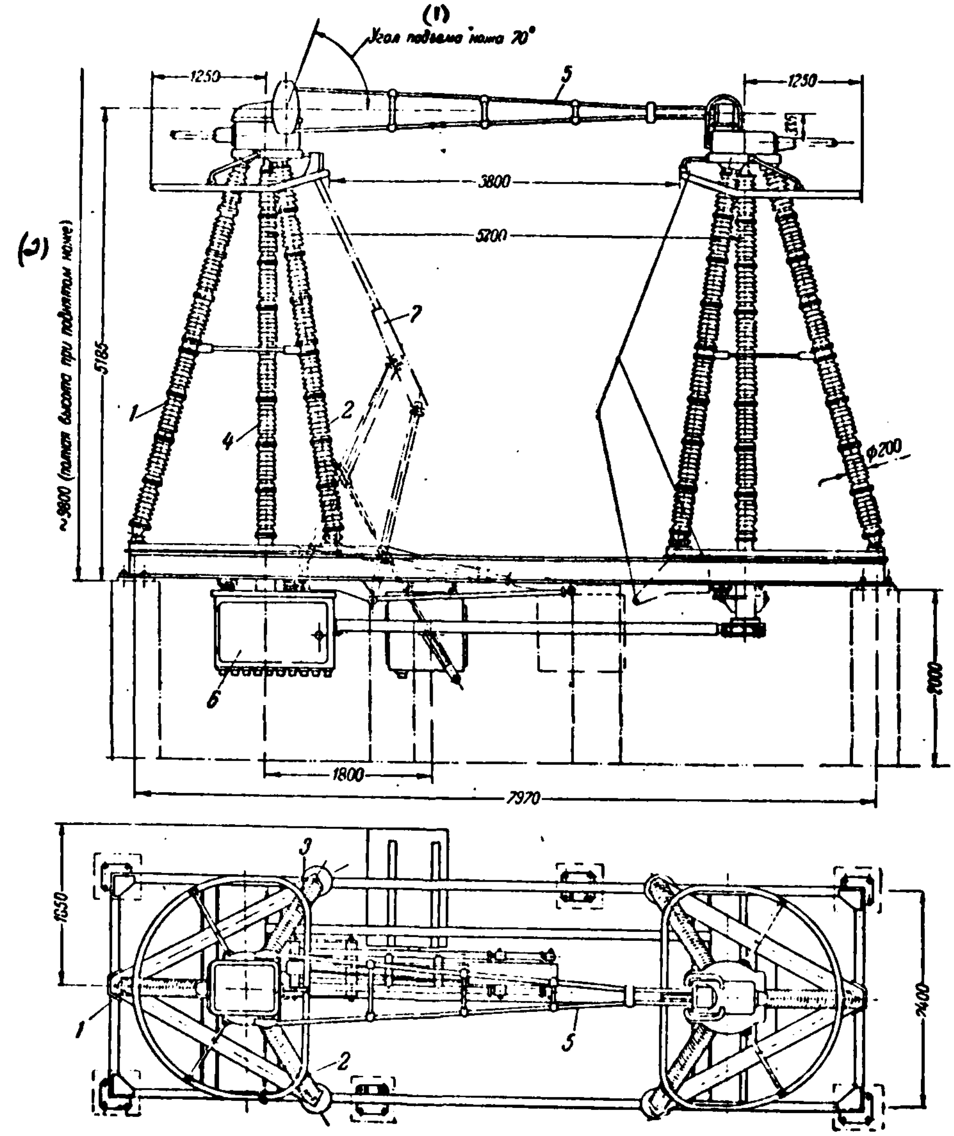

Fig. 16-9. Disconnector on 400 kV, 2000 A with the grounding knife (one pole).

Key: (1). Angle of ascent of knife. (2). (overall height with raised knife).

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For installations with voltage 110 kV the plant "electrical device" manufactures also one-shoe disconnectors of the type RLNO whose construction/design is proposed by eng. L. I. Dvoskin. Fig. 16-10 shows one pole of this disconnector for installation up on bed. These disconnectors are been commonly used with the rigid tubular busbars, arranged/located on different height (busbar 6 and 13).

Column 1 of the three pin insulators of the type ShT-35 is attached on rocker shaft arm 2. The latter is welded to the end/face of vertical shaft, which is located within cast iron support 3, which is the bearing of the column of insulators, which with process/operations with disconnector is turned around its vertical axis.

On the spot installations three poles connect up one tripolar disconnector with the aid of tubular TRG-4, hinged connected with rocker shaft arms 2.

On the upper insulator of column 1 is established/installed cast

iron cap 5, in which are placed bevel gears of the mechanism of the motion of the knife of disconnector (diagram while in Fig. 16-10). On this cap there are terminals/grippers for the fastening to it of the tubular busbars of 6 distributors. Therefore during the rotation of shoes of insulators cap 5 remains fixed.

In cap 5 is side shaft 20, at brought-out outside end/lead of which is established/installed leading lever 7, connected with the framework of 8 mechanisms of the motion of the knife which is carried out just as the mechanism of a disconnector of the type RLN, dismantled/selected higher and given in Fig. 16-6 (leading lever of 7 single-shoe disconnectors fulfills the functions of the leading lever 18 of disconnector of the type RLN).

Fixed contacts 11 are established/installed on welded bracket 12, fastened/strengthened to upper tubular busbar 13. Horns 14 provide the correct entry of knife in fixed contacts. With flexible busbars bracket 12 with contacts 11 they fasten on the supplementary column of stand-off insulators.

Within cap 5 are located (Fig. 16-10a) vertical 17 and horizontal 20 shafts, inserted into brass bearings 18, pressed into the housing of cap. Shafts are connected with bevel gears 19. To the lower end/face of vertical shaft is welded disk 16, rigidly attached

to the cap/hood of 15 upper insulators of column 1.

Thus, during the rotation of column 1 together with it rotates vertical shaft 17. In this case cap 5 remains motionless, since it is held by fixed to it rigid tubular busbar 6. From shaft 17 through gears 19 rotate side shaft 20 and leading lever 7. During the rotation of the latter framework 8 at first turns knife 9 around its axis to the angle approximately/exemplarily 80°, and then are abstracted/removed it in vertical plane at an angle of of 60° (position 10).

Upon the inclusion the motion occurs in the reverse order: first knife without impact enters into fixed contact, and then is turned by its flat/plane cap it wedges jaws.

Are recently in the Soviet Union developed also single-shoe disconnectors to voltage 35 kV and cantilever type disconnectors to voltage 220 kV (see Vol. 2, chapter 10). In those, etc. the mechanism of the motion of the knife in principle of the same as the dismantled/selected single-shoe disconnectors have 110 kV with a somewhat distinct overall design.

Foreign firms manufacture the simplified disconnectors single-shoe with the folding knives (similar to the grounding knives

in Fig. 16-7 and 16-9), and also with pantographic knives (see Vol. 2, chapter 10), which are similar to pantographic current pickups of electric locomotives and electrical trolleys, and other constructions/designs (l. 16-3).

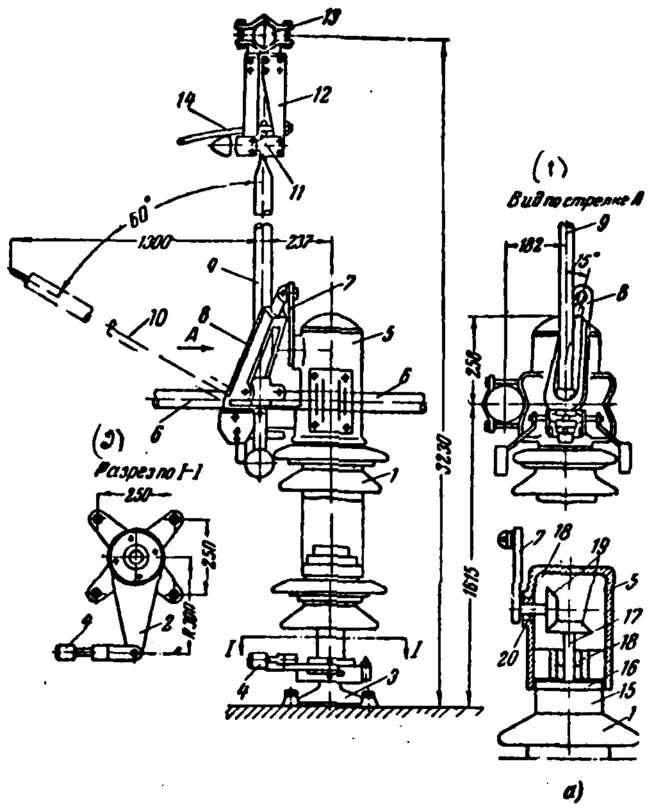

Fig. 16-10. Disconnector is single-shoe of the type RLNO-110 on 110 kV, 600 (one pole). a) the schematic diagram of cap.

Key: (1). View of firing. (2). Section/cut on.

16-4. Drives of disconnectors.

Recently in the distributors of stations and substations are installed predominantly tripolar disconnectors with drives. The use/application of drives raises the safety of the fulfillment of process/operations with disconnectors, since drives are installed at a distance from disconnectors, and in the closed distributors will carry into the corridors controls (Fig. 16-11). Drives simplify and accelerate the fulfillment of process/operations with disconnectors as a result of simultaneous inclusion/connection and cutoff/disconnection of all phases.

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The presence of wires on disconnectors permits implemention of blocking the drives of disconnectors and drives of the switches (see Vol. 2) how are prevented incorrect process/operations with disconnectors (process/operation for current with the connected switch). Similar blockings increase the reliability of operation and the safety of servicing installation.

For control of disconnectors are applied manual, electric-motor and pneumatic drives.

Is most common manual rigging, which finds use/application for disconnectors to rated currents to 3 kA inclusively.

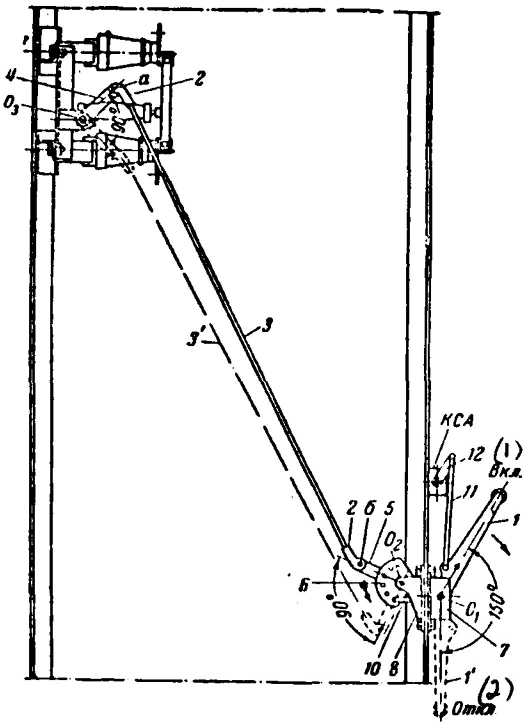
One of the versions of the installation of rigging is shown in Fig. 16-11; the diagram of drive is given in Fig. 16-12. On axis O_1 of the main bearing 7 of drive is put on handle 1, in lower part of which is finger/pin 9. To axis O_2 of tail bearing of 8 drives are put on rigidly connected with each other levers 5 and 6. Lever 6 and finger/pin 9 hinged (c and d) are connected with lever 10. To Fig. 16-11 the right side of lever 10 and finger/pin 9 they are not visible, since they are located within drive, but lever 6 is carried out in the form of sector with the series/row of the arranged/located in circumference openings/apertures. Lever 5 is fastened with sector 6 by bolt, inserted into one of its openings/apertures.

Lever 5 and rocker shaft arm 4 on shaft O_3 of disconnector is hinged connected with tube by 3 (with the aid of plugs 2).

In linkage 9-10-6 (Fig. 16-12) the lever (finger/pin) 9 is leading, lever 10 performs the role of connecting rod, and lever (sector) 6 is the driven/known component/link; in linkage 5-3-4 lever 5 is leading, thrust/rod by 3 performs the role of connecting rod, and lever 4 is leading.

In Fig. 16-11 and 16-12 by solid lines is marked the position of levers with the connected disconnector, but by dotted lines - with off disconnector. Rifleman/pointers showed the direction of rotation of levers with the cutoff/disconnection of the disconnector when handle 1 they turn downward at an angle of of 150°. To the same angle is turned finger/pin 9; sector 6 with lever 5, and also lever 4 they are turned at an angle of of 90°.

In the connected position of disconnector the angle between lever 4 and connecting rod 3 is close to 90°, thanks to which the moment/torque on the shaft of disconnector at the end of the process of the inclusion or in the beginning of the process of cutoff/disconnection has value, close to maximum.



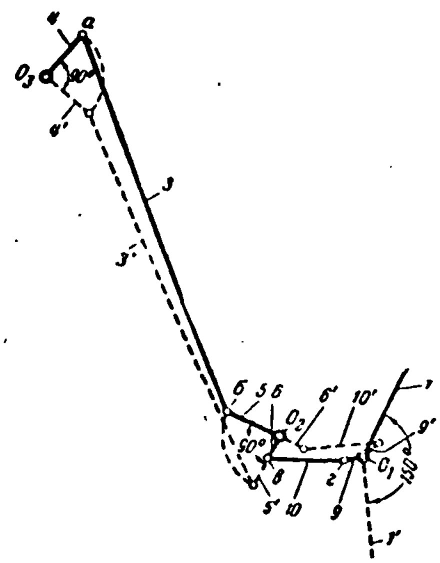


Fig. 16-11.

Fig. 16-12.

Fig. 16-11. Control of tripolar disconnector with the aid of manual rigging.

Key: (1). on. (2). off.

Fig. 16-12. Schematic of rigging of Fig. 16-11.

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In the same position of disconnector leading levers 9 and 5 and corresponding to them connecting rods 10 and 3 are located in position, close to dead (levers 9 and 10 even will begin to fall to dead center). Therefore is eliminated the possibility of displacing of levers and cutoff/disconnection of disconnector under the action of the appearing with course short-circuit current of the electrodynamic effort/force, which strives to disconnect the knife of disconnector.

In main bearing 7 is a trip, which locks drive in its end positions.

Openings/apertures in sector 6 are necessary for selecting the necessary position of lever 5 with the realization of transmission from drive to disconnector.

In the diagram of Fig. 16-12 direction of rotation of leading component/link 9 (clockwise) and driven/known 6 (counter clockwise) are opposite. This transmission system is mainly used when the disengagement shaft O_3 is placed above drive axle O_2. If disengagement shaft O_3 is located at the same height as axle O_2 or below it, the rear drive bearing 8 is turned, as a result of what components/links 9 and 6 drives rotate already in one direction (clockwise).

Fig. 16-11 shows the setting of blocking contacts of the type KSA. In the case of contacts are several pairs (from 2 to 12) of

fixed contacts and the same number of turned contacts, attached on general/common/total cylinder. On the end of the latter is rocker shaft arm 12, connected with steel thrust/rod by 11 with the handle of 1 drives. Simultaneously with the rotation of handle 1 rotates cylinder KSA, as a result of which occurs the closing/shorting and interrupting its fixed contacts. These contacts, which are usually called blocking-signal or blocking contacts, utilize in the diagrams of signaling, automation, etc. In the form of an example Fig. 16-13 shows the use of blocking contacts BK for the signaling of the position of tripolar disconnector with the aid of two tubes (for greater detail, see Vol. 2, chapter 16).

Blocking contacts are established out of cubicles so that they would be open-door without stress relieving with disconnector and adjacent electrical equipment (Fig. 16-11), in this case wiring secondary circuits is obtained more simply, shorter and is placed out of cubicle.

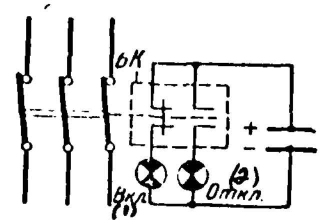

Fig. 16-13. Diagram of the signaling of the position of disconnector with the aid of tubes.

Key: (1). On. (2). Off.

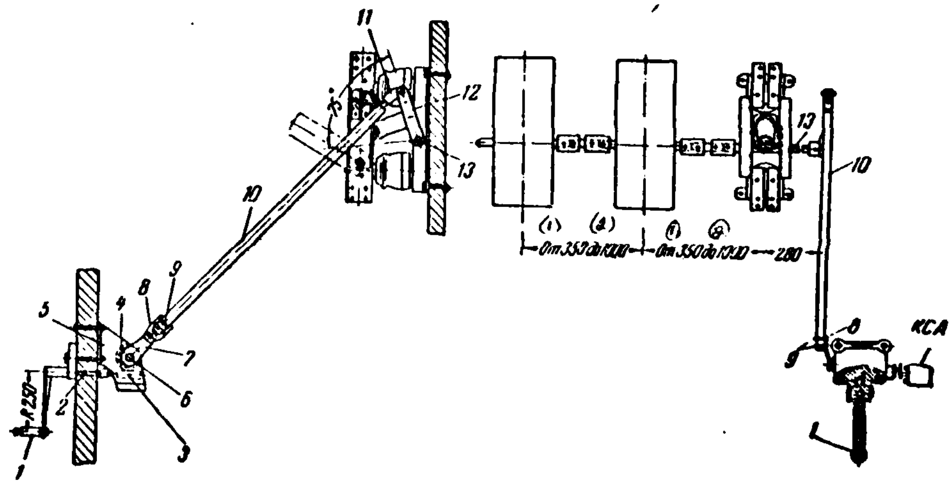

Fig. 16-14. Control of tripolar disconnector of type RVK-10/3000 with the aid of manual worm gear of type PCh-50.

Key: (1). From. (2). to.

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Manual worm gears (Fig. 16-14) are applied for control of heavy disconnectors, for example by disconnectors for internal setting to rated currents 3 kA and more.

On the axis of 6 tail bearings of 5 drives is mounted worm gear 4, engaged with worm 3 at shaft butt end of 2 handles 1. At the end/lead of the same axis is mounted lever 7, hinged connected with plank 8. The latter with the aid of two clamps 9 is rigidly connected with thrust/rod by 10 (gas tube), which with the aid of bent plug 11 is hinged connected with rocker shaft arm by 12 on the shaft of 13 disconnectors.

The rotation of handle 1 by means of worm 3 is transmitted to worm gear 4. For cutoff/disconnection or including the disconnector it is necessary to turn worm gear 4, and together with it and lever 7 to angle of 180°. Upon the inclusion/connection of disconnector handle 1 they revolve clockwise, while with cutoff/disconnection - vice versa.

Electric-motor drives are applied if necessary for remote control of disconnectors from control board. They are considerably more complicated and more expensive than hand drives; therefore they are applied mainly for control of the very heavy tripolar disconnectors of the internal installation (usually on 3 kA and more)

and of the disconnectors of external installation by voltage 110 kV and above.

Fig. 16-15 shows the installation of electric-motor drive 1 for control of a tripolar disconnector of the type RVK on 20 kV and 5 kA. From the shaft of electric motor the motion is transmitted through gears and worm to worm gear 2 (it is shown by the dotted line), on shaft of which is established/installed rocker shaft arm 3. The latter with the aid of thrust/rod by 4 is connected with rocker shaft arm by 5 on the shaft of the disconnector (structurally/constructurally transmitted from the shaft of worm gear to the shaft of disconnector is carried out, just as in the worm gear - see Fig. 16-14).

The process/operations of inclusion/connection and cutoff/disconnection are conducted by the rotation of engine in one direction; in this case rocker shaft arm 3 for the completion of each process/operation is turned on 180°. Electric motor is disconnected automatically by interrupting by a special blocking contact of the circuit of the electromagnet of the intermediate contactor, through which is supplied the engine (Fig. 16-16).

In the case of the damage of electric motor the disconnector can be switched on and disconnected with the aid of free handle.

Electric-motor drive supply with the electric motor of direct or alternating current in power 0.52-1 kW and voltage 110-380 V.

The schematic diagram of control of electric-motor drive is given in Fig. 16-16, where the mechanical feature of the drive is shown conditionally. It is assumed that upon inclusion/connection the lever RB is moved to the right, and with cutoff/disconnection - to the left. Engine in both cases rotates to one side. Diagram is supplied from the storage battery through the busses of control ShU, laid on control board, and busses of the inclusion ShV, laid in distributor near the site of installation of the drive of disconnector.

For control of the electric motor of drive apply pushbutton or rotary keys/wrenches the controls. In the diagram of Fig. 16-16 for the purpose of simplification is shown the simplest key/wrench of the control KU, which consists of two normally extended knobs/buttons with spring self-reset - knob/button of inclusion/connection V and knob/button of cutoff/disconnection O.

Disconnector in the diagram is shown in off position.

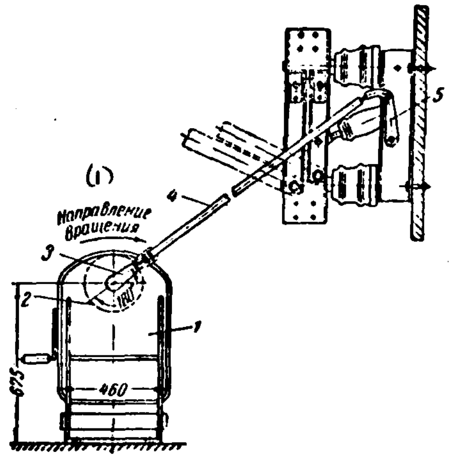

Fig. 16-15. Control of a tripolar disconnector of the type RVK-20/5000 with the aid of electric-motor drive of the type MRV.

Key: (1). Direction of rotation.

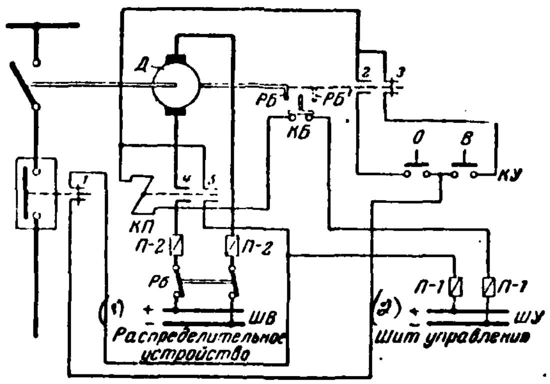

Fig. 16-16. Schematic diagram of control of disconnector with the aid of electric-motor drive.

Key: (1). Distributor. (2). Sheet rubber of control.

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Upon the remote switching of disconnector by knob/button V they close the circuit: plus ShU-P-1 - blocking contacts of 1 drives of switch - contacts of knob/button V - block contacts 3 of drive of disconnector - the holding magnet of contactor KP - blocking contacts KB of the electric-motor drive of disconnector - P-1 - minus of ShU. Is included contactor KP and are simultaneously closed its contacts 4 and 5. Auxiliary contacts 5 serve for guaranteeing the prolonged feed of electromagnet KP, since blocking contacts 3 are broken in the beginning of the course of including the disconnector when the engine of drive still must work (current circuit: plus of ShU - P-1 - contacts 5 - electromagnet KP - blocking contacts KB - P-1 - minus of ShU).

Toward the end of the course of inclusion/connection (with certain lead/advance) the lever RB, being moved to the right, breaks contact KB, after which is disconnected the contactor KP and is terminated the feed of the electric motor of drive. Engine, continuing to rotate on inertia, presses home the knives of disconnector. In the connected position blocking contacts 3 are extended, and 2 - are closed. Contacts KB have return spring;

therefore they will be locked; in this position the lever RB is located to the right of contacts KB (indicated by dotted line position RB').

For the cutoff/disconnection of disconnector by the knob/button of key/wrench O they close the circuit of the electromagnet KP, which switches on the feed of electric motor. Toward the end of the course of the cutoff/disconnection of disconnector the lever RB, being moved to the left (from position RB'), breaks contact KB, after which is disconnected KP and ceases the feed of electric motor. The latter, continuing a little to rotate on inertia, leads the knives of disconnector to end position.

Should be emphasized the importance of the correct control of the moment/torque of interrupting the blocking contacts KB of drive. It is necessary that they would be broken with such lead/advance with which the engine, rotating on inertia, would provide full/total/complete cutting or thinning of the knives of disconnector.

In the case of the late interrupting of contacts KB with the cutoff/disconnection of disconnector its knives will prove to be incompletely dilute, and upon inclusion/connection - by incompletely thrown in. The latter can lead to their dangerous overheating in

further work.

Blocking control circuit through the blocking contacts of 1' drives of switch pursues the target of avoiding inclusion/connection or cutoff/disconnection of disconnector with the connected switch.

The signaling of the position of disconnector in the diagram of Fig. 16-16 is not shown.

The pneumatic drives, which work in the compressed air, are applied for remote control of any disconnectors. Construction/design their very is simple and reliable. The principle of the device/equipment of the pneumatic drive is shown in Fig. 16-17.

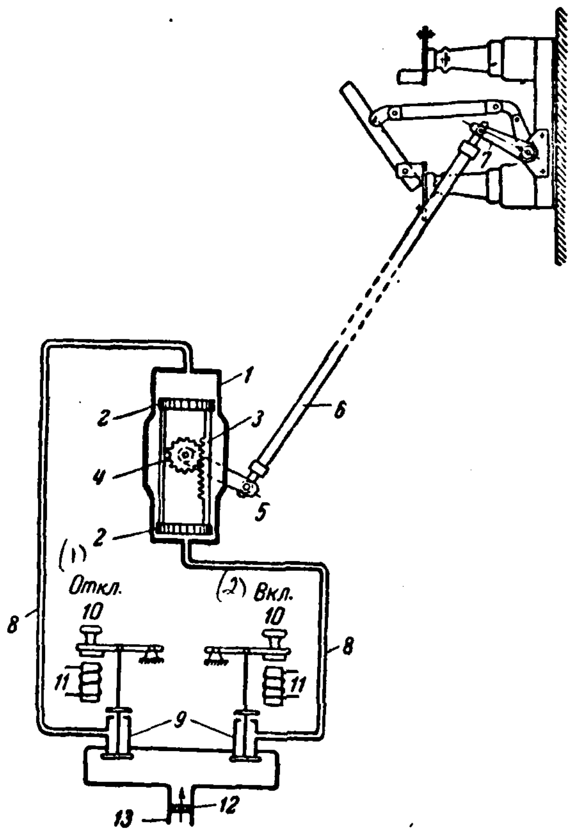

Fig. 16-17. Schematic diagram of the device/equipment of the pneumatic drive to disconnector.

1 - cylinder of the drive; 2 - pistons, rigidly connected with each other; 3 - rack, moving with piston stroke; 4 - gear, engaged with the rack; 5 - rocker shaft arm on the axis of teeth (out of cylinder 1); 6 - thrust/rod; 7 - rocker shaft arm of the disconnector; 8 - conduits/manifolds; 9 - valves; 10 - knob/button for the manual

operations; 11 - electromagnets for the remote process/operations; 12 - filter; 13 - conduit/manifold from blowing plant.

Key: (1). Off. (2). On.

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Chapter seventeen.

HIGH-VOLTAGE SWITCHES.

17-1. Technical characteristics. Types.

Switches by voltage are above 1000 V (further high-voltage), intended for inclusion/connection and cutoff/disconnection of the electrical circuits of high load stress and also for their cutoff/disconnection during short circuits must possess the sufficient cutoff ability, least possible by time actions, by high reliability of operation. They must be explosion- and flame-resistant, simple by construction/design and they are convenient in the operation; sizes/dimensions, weight and their cost/value must be possibly less. Switch must maintain/withstand the established/installed by norms number of process/operations without the need of controlling of its mechanism or replacement of its separate parts.

The fundamental parameters of high-voltage switches as other electrical devices, are nominal voltage, great working voltage and

rated current. Furthermore, high-voltage switches are characterized by the rated current (nominal power) of cutoff/disconnection and by the rated current of inclusion/connection.

The rated current of cutoff/disconnection $I_{\text{отк.ном}}$ characterizes disconnecting ability of switch. This is that maximum current which switch can reliably disconnect with the voltage, equal to its nominal voltage, without any damages or strains, which block its further exact work; in this case in the oil breakers must not be of excessive oil throwing from gas vents, but in gas switches - flareback beyond the limits, indicated by plant.

In operation cases occur, when switch to two-three times is included to the existing in network/grid short circuit with the subsequent automatic cutoff/disconnection. Based on this, the rated current of the cutoff/disconnection of switch defines experimentally as that maximum current of three-phase short circuit with which the switch maintains/withstands the following cycle of process/operations, established/installed by GOST [All-union State Standard] 687-41 to the high-voltage switches:

$$O-180-BO-180-BO, \quad (17\text{-}1)$$

where O - designates the process/operation of automatic cutoff/disconnection by the switch of short-circuit current (from the connected position) with relaying without time element;

VO - designates the process/operation of inclusion/connection to short circuit of off position and the immediately following after it (without time element) process/operation of the cutoff/disconnection;

180 - designate time interval 180 s between consecutive process/operations.

The value of the rated current of the cutoff/disconnection of switch determines in essence the construction/design of its arc-suppression device/equipment.

The maximum current which switch can reliably disconnect under the same conditions, but with the voltage, different from its nominal voltage, call current the cutoffs/disconnections of switch $I_{отк}$.

The limiting current of the cutoff/disconnection of switch is called the great value of its current of cutoff/disconnection with certain subnormal voltage.

The disconnecting ability of switch they characterize also by the nominal power of the cutoff/disconnection:

$$S_{отк.ном} = \sqrt{3} I_{отк.ном} U_{вык.ном}, \qquad (17\text{-}2)$$

and with the voltage, different from the nominal voltage of switch, by the power of the cutoff/disconnection:

$$S_{\text{отк}}=\sqrt{3}I_{\text{отк}}U_{\text{уст.ном}}. \qquad (17\text{-}3)$$

Since the inclusion of switch is possible to the existing in network/grid short circuit, then for switches is established/installed also the specific value of the rated current of the start, under which is understood that greatest short-circuit current, which switch, can reliably include/connect with nominal voltage without the sticking of contacts and without any other the damages, which block its further exact work.

The value of the rated current of the start of switch is determined by the construction/design of the contacts of switch and by the driving power, employee for its start.

In chapter 6 it was indicated the importance of the rapid cutoffs/disconnections of short circuits in powerful/thick power systems, which is possible only with the short tripping time of switches. The tripping time of switch with drive is determined by time interval from the closing a circuit of the disconnecting electromagnet of drive (from cycling on cutoff/disconnection) to final arc extinction in all phases of switch.

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The tripping time of switch $t_{в}$ consists of the proper time of the cutoff/disconnection of switch with drive $t_{c.в}$, equal to time from the moment/torque of the closing a circuit of the disconnecting electromagnet drive to the beginning of the disagreement of the arcing contacts of switch, and the time of extinction of arc in switch $t_{д}$, i.e. $t_{в}=t_{c.в}+t_{д}$.

Low-speed switches have proper time of the cutoff/disconnection of approximately/exemplarily 0.1-0.15 s, and tripping time 0.15-0.25 s; quick-break switches have the proper time of the cutoff/disconnection of order 0.03-0.05 s, and tripping time 0.05-0.08 s.

High-voltage switches, as all other electrical devices, must be electrodynamically and thermostable with the greatest possible in this installation short-circuit currents (for greater detail, see chapter 21). In the case of insufficient stability are possible the damages of the individual parts of the switch as a result of the excessive forces of interaction between current-carrying parts and the inadmissible heating of the latter; possibly also welding contacts.

By kind of installation distinguish switches for internal and external installations.

On the kind of the arc-arresting medium all high-voltage switches can be subdivided into two basic groups; 1) liquid switches - oil and water and 2) gas switches - auto-gas (with solid gas-generating material), air (with the compressed air), etc.

Most widely used and most diverse in design are the oil breakers which in turn, can be subdivided into: 1) oil bulk-oil breakers (multi-volumetric or tank) and 2) oil breakers with small space of oil (small volume).

In the first oil (transformer) is utilized for the extinction of the electric arc, which appears between contacts with cutoff/disconnection, and for the insulation of current-carrying parts of each other and of the grounded tank. The secondly oil is utilized only for the extinction of nonsense, and the insulation of current-carrying parts is realized with the aid of air and ceramic or organic insulation.

The water switches, in which for an arc extinction is utilized the water, are structurally/constructurally similar to small volume oil breakers. As a result of the number of the inherent in them

deficiencies/lacks, fundamental of which are the volatility of water, the higher in comparison with oil freezing point of water, which impedes the use of water switches in unheated areas and in the open air (during addition to water of glycerin or ethylene glycol the freezing point of water composes minus 15 - minus 25° C), and difficulty in the achievement of the proper insulation with voltage is more than 35 kV, water switches with Soviet plants are not manufactured and therefore further they are not examined.

In gas switches the insulation of current-carrying parts of each other and of the grounded elements of the construction/design of switch is fulfilled with the aid of air and different ceramic and organic insulation.

In special group must be isolated the so-called switches of load, intended for the cutoff/disconnection only of the currents of load and not intended for the cutoff/disconnection of short-circuit currents. In these switches can be used different arc-suppression devices/equipment.

Soviet plants manufacture the switches of load with explosion chambers with solid gas-generating substance.

17-2. Oil bulk-oil breakers.

General information. Until recently multi-volumetric oil breakers were most widely used on the operating electrical devices. However, as a result of the inherent in them essential deficiencies/lacks, about which it is shown below, latter/last time they to a considerable degree are displaced by the more advanced small volume oil breakers and switches gas.

Multi-volumetric oil breakers subdivide into switches from switches with simple (free) disruption arcs in oil (without arc-suppression chambers/cameras) and to switches with the arc-suppression chambers/cameras, which accelerate arc extinction and which increase the disconnecting ability of switch.

Basic parts of multi-volumetric oil breaker they are (Fig. 17-1): tank 1, filled to certain oil level 25, cover/cap 9, wall entrance insulators 8, drive mechanism 16-23 contacts 13-14. For the purpose of providing safety of maintenance/servicing metallic tank and cover/cap of switch ground.

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In multi-volumetric oil breakers by voltage not higher than 10

kV all three phases are placed in one tank (one-tank switches), which has rectangular (Fig. 17-1) or circular (Fig. 17-2) form. More durable are round tanks with spherical bottoms.

In switches with voltages 35 kV and higher each phase it is placed in the separate tank (three-tank switches) of circular (Fig. 17-9) or oval (Fig. 17-6) form. In recent years to the tanks of switches to very high voltages frequently is given elliptical or lens-shaped form (Fig. 17-11) how are reached the considerable decrease of overall sizes, space oils and weight of switches. In all cases the tanks are welded made of boiler steel.

The internal surface of tank is insulated by one or several layers of plywood or insulating cardboard (2 in Fig. 17-1) for warning/preventing the overlap from contacts to tank. In one-tank switches, furthermore, are fulfilled interphase partitions for the more reliable insulation of phases.

Tank is supplied with oil-level gauge, usually in the form of glass tube with 3, by oil-flow tap/crane 26 by plug 7 for the additional filling of oil.

On the internal surface of the cover/cap of switch are fastened motionless parts of it of the drive mechanism: shaft bearings 23,

guides 19, etc.

The covers/caps of switches to voltages to 35 kV inclusively cast themselves from cast iron. In the large rated current of switch the cover/cap can be heated considerably by eddy currents, also, as a result of hysteresis. For eliminating this the covers/caps of such switches cast themselves from non-magnetic cast iron.

Switch tanks to 35 dv inclusively are suspended to bolted caps or pins 6, passed into openings/apertures in the inflows/bosses of 5 covers/caps and in lugs 4, welded to Baku (Fig. 17-1). In cover/cap there is a deepening with packing layer, into which enters the upper edge of tank.

Switches to 35 kV inclusively are suspended in distributors on metal constructions (Fig. 17-6). For this on covers/caps there are inflows/bosses with bolt holes (Fig. 17-2). The height of the installation of these switches must be such that with the omitted tank would be provided access to contacts. For lift and settling of tank with oil these switches have a special lift lever/crank device/equipment or a hoist with cables.

Heavy multi-volumetric oil breakers by voltages 110 kV and higher are installed in foundations. The tank of this switc' they

attach to bed by the bolts, passed through the special feet, welded to the lower part of the tank (Fig. 17-4). The covers/caps of multi-volumetric switches on 110 kV and higher are welded made of boiler steel and are welded on to the upper edge of tank. For penetration inside tank (after oil drain) is provided for the hatch (access) in the wall of tank (Fig. 17-8) or in its cover/cap.

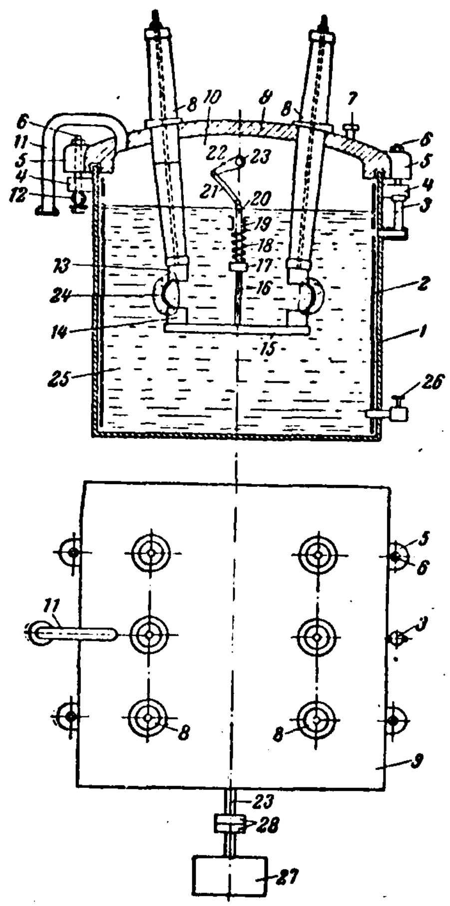

Fig. 17-1. Schematic outline of oil bulk-oil breaker without arc-suppression chambers/cameras.

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The covers/caps of switches have spherical form. Wall entrance insulators are established/installed inclined with purpose of an

increase of the distance between current-carrying parts in air. Insulators are secured in cover/cap with the aid of collars and bolts without the use/application of the cementing materials.

Wall entrance insulators of switches to 10 kV inclusively porcelain (Fig. 17-2). In wall entrance insulators of switches on 35 kV (Fig. 17-14) all over length of the current-carrying rod is superimposed laminar bakelite insulation. The exterior of the insulator is equipped with the porcelain cover whose internal cavity is filled with insulating compound. Switches on 110 kV higher have oil-filled wall entrance insulators with the condenser/capacitor bakelite insulation of the current-carrying rod (copper tube). At the external end/lead of this insulator is a glass expander (Fig. 17-4), which performs also the role of oil-level gauge. The internal cavities of wall entrance insulator and tank between themselves are not communicated.

All multi-volumetric oil breakers by voltages 35 kV and higher have built-in current transformers. Cores with secondary windings are put on to the internal part of wall entrance insulator and are fastened/strengthened under the cover/cap of switch (Fig. 17-4). As primary winding serves the current-carrying rod of wall entrance insulator (see also §19-3).

Since oil in multi-volumetric oil breakers serves not only for an arc extinction, but also for the insulation of current-carrying parts, then to it present very stringent requirements both in the relation to dielectric strength and in the relation to any admixtures/impurities, adversely affecting the insulation and the current-carrying parts. Since in the process of operation oil is soiled and is moistened, its quality should be systematically checked via sampling for testing. Oil, which does not satisfy the requirements of norms, they clean or replace by fresher.

The large space of oil in these switches leads to the need for having in operation the large reserves of fresh oil and device/equipment for cleaning/purification of decanted from switches oil.

Multi-volumetric switches have considerable weight and overall sizes. So, the total weight of three phases, manufactured at present with the Soviet plants of multi-volumetric oil breakers on 110 kV, is 18.3 t with the weight of oil 8.5 t, and the weight of switch 220 kV - 90 t with the weight of oil 48 t.

Control of oil breakers, i.e. start and their cutoff/disconnection, is conducted by the special drives, examined in chapter 18.

Multi-volumetric oil breakers with the simple (free) disruption of arc in oil (without arc-suppression chambers/cameras). Fig. 17-1 gives the schematic outline of cross section on one phase of this multi-volumetric oil breaker. Switch is shown during cutoff/disconnection.

Fixed contacts 13 are fastened/strengthened to the butt ends of the current-carrying rods of wall entrance insulators 8. The slide contacts of 14 two disruptions of the phase of switch are established/installed on current-carrying contact crosshead 15, which using rod 16 of insulation (bakelite, tree/wood) is fastened/strengthened to metallic crosshead 17. To the latter are fastened/strengthened the contact pole arms of all three phases of switch; therefore during the motion of crosshead 17 upward or downward together with it in the same direction are moved contact pole arms 15 and slide contacts of 14 three phases of switch.

The rotary motion of shaft 23 is converted into rectilinear motion of slide contacts with the aid of crank-connecting rod mechanism, which consists of fastened/strengthened to lever shaft 22 and hinged connected with it connecting rod 21. The latter in turn, is hinged connected with metallic thrust/rod 20, moving in guides 19,

at butt end of which it is attached pole arm 17. On thrust/rod 20 is put on disconnecting spring 18.

For start and cutoff/disconnection of switch serves drive 27 whose shaft with tne aid of two half-couplings 28 is connected with the shaft of switch 23. Upon start the drive turns the shaft of switch clockwise, also, with the aid of the crank mechanism 21 and 22 and thrust/rod 20 of crosshead 17 together with slide contacts are moved upward - contacts 13 and 14 are closed. Disconnecting spring 18 is presssed. In the connected position the switch is held by locking actuator.

With the cutoff/disconnection of switch by hand or with the aid of the disconnecting electromagnet they act on locking actuator which frees/releases the movable system of switch (shaft 23), after which under the action of the disconnecting spring 18 crosshead with slide contacts are moved downward - contacts 13 and 14 diverge. To cutoff/disconnection it contributes the dead weight of slide contacts and pole arms.

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Thus, the rate of the disagreement of the contacts of switch does not depend on the constructicn/design of drive and action of person, who

disconnects switch.

With the cutoff/disconnection between movable and fixed contacts appears arc 24. Since to each phase there are two pairs of contacts, then arc appears simultaneously in two places - appear two consecutive arcs to phase.

Oil 25 near arc under the action of its high temperature evaporates and is decomposed/expanded into composite/compound component parts, in consequence of which the arc proves to be surrounded gases, i.e. it burns within the gas pocket, filled with oil vapors (to 40o/o of space of bubble) and with products of its decomposition, which contain to 70-80o/o of hydrogen.

Initially gases are formed around arc very rapidly (hundredth fractions of a second), in consequence of which the pressure in the gas pocket rapidly grows to several atmospheres, and it can reach 5-10 atm(tech) [19-1].

This pressure is transmitted to which surrounds bubble oil, and through it to the walls and to the bottom of tank, which must be sufficiently mechanically durable. If switch was closed hermetically and above the oil level it would not be airspace, then with the onset of arc it inevitably would explode. Therefore between the surface of

oil and the cover/cap compulsorily is left not filled by oil buffer space 10, which has communication/report with the surrounding air through gas vent 11 (space of buffer space composes 20-30o/o of tank volume).

In the presence of buffer space in proportion to the build-up/growth of the gas pockets around the arcs of the disruptions of switch oil can be moved upwards, filling buffer space and displacing from it air outside through the gas vent. Therefore decreases the pressure, transmitted to the walls and the bottom of tank.

Thus, in oil breaker the arcs of disruptions burn not in oil, but in the gaseous medium, which contains hydrogen. The latter, as is known (chapter 13), possesses best in comparison with other gases arc-arresting properties. The deionizing ability of gases is amplified because of elevated pressure in the gas pocket.

To the deionization of arc to a considerable degree contributes the eddy-like flow of gases within bubble, caused by gassing on the surface of the latter. With the large disconnected currents the gas formation and the intensity of the eddy-like flow of gases are amplified both as a result of the higher temperature of arc and as a result of the fact that the arcs of disruptions are bent and are

moved within bubbles in the direction of the walls of switch tank (Fig. 17-1). This displacement/movement of arcs occurs, in the first place, under the action of the electrodynamic repulsive forces of arcs currents of both disruptions of the phase (currents have opposite direction), and, in the second place, under the effect of the mass of the steel wall of tank, to which pulls the arc, about which it was said into §13-2 (Fig. 13-7).

During the motion of arc within the gas pocket it is moved from the more heated region of bubble in that less heated; the approximation/approach of arc to the surface of bubble amplifies the evaporation of oil, and towards arc intensely are rejected all new masses of the relatively cold and unionized gases, which deionize arc. The deionization of arc is amplified also on measure of deviation of the contacts of switch.

Is most violently the process of deionization proceeds at the moments of arc extinction upon transfer of the current through the zero value when power supply to arc gap ceases and the temperature of the latter rapidly descends, as a result of which thermal ionization in arc gap ceases, and the deionization of gases sharply is amplified.

If the distance between contacts is small, then it is possible

that for the short time of arc extinction with the passage of the current through zero arc gap is deionized the arc into the following half-period it will be insufficiently and ignited again (§13-2).

Arc does not repeatedly ignite only if at the subsequent moments of time after its extinction at current zero the rate of an increase in dielectric strength of gap/interval remains always of more than voltage recovery rate on the contacts of switch. This occurs only with specific distance between the contacts of switch, which depends on its type.

From the aforesaid it follows that the lifetime of arc in switch depends on the rate of the disagreement of contacts. In multi-volumetric switches the average speeds are 2-4 m/s. In the simplest switches in question the arc can last to 10-15 half-periods (0.10-0.15 s).

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As a result of prolonged arcing similar switches are low-speed and cannot disrupt large short-circuit currents.

By an increase in the number of places of disruption in the phase (4-6 and more) it is possible at the same rate of the motion of

contacts to achieve larger arc length, and consequently, the decrease of the arcing time and increase in the disconnecting ability of switch. As a result of the considerable complication of contact system multiple break was not widely applied in multi-volumetric oil breakers with the simple disruption of arc in oil. The Soviet plants of such switches do not manufacture.

After final arc extinction the gas pocket gradually rises upwards and it enters into buffer space under the cover/cap of switch (Fig. 17-1). Since hydrogen in mixture with atmospheric oxygen forms detonating gas, then for preventing the blast of the latter in buffer space is necessary that gases, passing through the layer of oil above the contacts of switch, would have time sufficiently to be cooled. Furthermore, with a small layer of oil above contacts are a danger of breach/inrush by its gases of bubble in the process of cutoff/disconnection, which also can be the reason for the blast of oil breaker.

It was above indicated that in the process of cutoff/disconnection, in proportion to the develcpment of the gas pockets around the arcs of disruptions, oil is moved upwards, filling buffer space. The oil level in switch must be such that with the disruption with the switch of the established/installed for it current of cutoff/disconnection the process of arc extinction and the

lift of oil would conclude earlier than oil will fill entire the buffer space. Otherwise after the displacement of entire air from buffer space the pressure in tank will greatly rapidly grow and it can explode. In order to avoid this, on the covers/caps of some multi-volumetric oil breakers are provided for emergency (protective) valves. With an increase of the pressure in switch tank to dangerous value the valve is opened/disclosed and oil by wide jet is discharged from under cover/cap outside.

Small switches frequently have the simple protecting device, shown in Fig. 17-1. In this case to coupling bolts 6 are put on thin-walled tubes with 12 which at a dangerous pressure in tank are mashed, and tank is omitted. Through the forming circular gap between the cover/cap and the tank oil is discharged outside.

Thus, the blasts of switches are possible both in the case of abnormal increase and in the case of abnormal lowering in the oil level. Therefore in the process of operating the multi-volumetric oil breakers it is necessary to very thoroughly follow the fact so that the oil level in tanks would not differ from by rated.

The blasts of multi-volumetric oil breakers are possible also as a result of internal overlaps in the switch between phases and between phases and tank, which is possible with the poor quality of

oil in switch (oil moistened or contaminated by the products of its decomposition under the action of the electric arc or oxidation products by its atmospheric oxygen, which is located under the cover/cap of switch and, etc.). The danger of the overlaps indicated increases because the forming around arcs gas pockets are filled with partially ionized gases, and also in view of the approximation/approach of arcs to the walls of tank. For the avoidance of the overlaps indicated, besides systematic careful quality control of oil, provide for, as noted earlier, the internal insulation of tanks (2 in Fig. 17-1), and in some switches also the partitions between phases.

The blast of multi-volumetric oil breaker is accompanied by the inflammation of oil. If are not accepted the measures, which block the spreading of burning oil, then in installation appears the fire, which is capable of completely deriving it from work. The spreading of burning oil it impedes the liquidation of emergency. The combustion of oil is accompanied by the isolation/liberation of an enormous quantity of smoke whose deposition on insulators can cause the overlap between phases or between phases and grounded metal constructions. For cleaning/purification from fume the installation must be long brought out from work. Therefore during the installation of multi-container of oil breakers in distributors must be carried out the definite requirements of fire safety (Vol. 2, chapter 7-10).

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The aforesaid makes it possible to draw the conclusion that the multi-volumetric oil breakers with the simple disruption of arc in oil are insufficiently ideal both as a result of the duration of the arc extinction and ability to disrupt comparatively small short-circuit current and as a result of the fact that they do not satisfy sufficiently the requirements of the reliability of the work of electrical devices, safety and easy servicing. Therefore in recent years of them they apply only in the installations of small power by voltage not more than 10 kV.

Fig. 17-2 shows the manufactured at present with Soviet plants oil bulk-oil breaker of the type VMB-10 (switch oil tank) to nominal voltage 10 kV and nominal power of cutoff/disconnection 100 MVA. Switch has round tank with spherical bottom. Inside tank is isolated/insulated by insulating cardboard. The partitions between phases are made also from insulating cardboard (in Fig. 17-2 they are not shown). Contacts end-type point. Fixed contacts 1 are carried out in the form of the massive copper blocks, screwed on ends of the current-carrying rods of wall entrance insulators. Slide contacts 2 are carried out spherical and are screwed on to the copper busbar,

which rests on the steel crosshead 4 of box section. Pressure in contact create springs 5.

Multi-volumetric oil breakers with arc-suppression chambers/cameras. The use/application of arc-suppression chambers/cameras accelerates arc extinction and reduces pressure in the tank of oil breaker, in consequence of which increases its disconnecting ability and reliability of operation.

In all contemporary arc-arresting devices/equipment of oil breakers in this or another form is utilized the gas blast, which ensures intense and rapid arc extinction.

Principle of device/equipment and fundamental parts of oil breakers with arc-suppression chambers/cameras in essence the same as and the multi-volumetric oil of switches with simple disruption arc in oil (Fig. 17-1). Are characterized by they mainly the presence and arc-suppression chamber design.

Multi-volumetric oil breakers with arc-suppression chambers/cameras had extensive application in Soviet installations with voltage 35-220 kV. Until recently in the installations indicated were applied oil breakers of the type MKP (oil breaker with chambers/cameras, substation), equipped with the arc-suppression

chambers/cameras of the longitudinal oil blast: on 35 kV of the type MKP-76, on 110 kV - MKP-160, on 154 kV - MKP-180 and on 220 kV - MKP-274. All these switches three-tank, intended for external installation. Despite the fact that their production is ended, let us examine their briefly device/equipment and work, since they are very common on the operating installations of the voltages indicated.

Fig. 17-3 schematically shows the arc-suppression chamber/camera of longitudinal oil blast, which was being applied in this series of switches, while on Fig. 17-4 - cross section on phase of one of the switches of series - an oil breaker of the type MKP-274 voltage 220 kV. From the latter it is evident that to each phase are established/installed two chambers/cameras 10 - on one on each wall entrance insulator 3.

Chamber/camera consists (Fig. 17-3) from upper metallic half-chambers 1 and partition 2 with openings/apertures and lower half-chambers 3, made from insulation, for example, from Textolite (in switches on 35 kV of the type MKP-76 chamber casing metallic, insulated inside by bakelite cylinders).

Chamber/camera is attached on the lower collar of 11 wall entrance insulators 10 and it is electrically connected with its current-carrying rod 12.

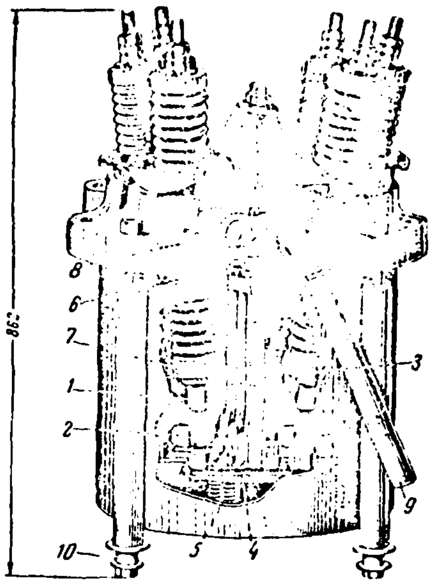

Fig. 17-2. An oil breaker of the type VMB-10 on 10 kV, 400 A, 100 MVA.

1 and 2 - motionless and slide contacts; 3 - wall entrance insulator; 4 - contact crosshead; 5 - contact springs; 6 - disconnecting springs; 7 - insulating rod; 8 - p ion indicator of the switch; 9 - the gas vent (it is displaced to side); 10 - protective thin-walled tube.

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In upper half-chamber is established/installed end-type contact 4, put on for stem guide 6; the latter is screwed into the housing of

upper half-chamber. The device/equipment of contact 4 is such, that it can be moved somewhat upward and downward on rod 6. Contact 4 is equipped with spring 5 and it is electrically connected by flexible member 9 with the housing of upper half-chamber.

Upon the start of switch hollow slide contact 14, fastened/strengthened to pole arm 13, enters into the lower opening/aperture of chamber/camera and, moving upward, it rests first in intermediate slide contact 7, and then together with it is continued motion to the contact of intermediate contact with upper 4, after which all three contacts is passed still certain path. Springs 5 and 8 are presssed (Fig. 17-3a).

With cutoff/disconnection the contacts are broken in reverse order. The first time after the start of contact 14 downward contacts 4 and 7 follow it, wringing out by springs 5 and 8. First reaches the backstop and is stopped front contact 4, after which downward continue to be moved only contacts 7 and 14. In this case between contacts 4 and 7 appears the arc (gas-generating), which evaporates and which decomposes/expands oil and which creates high pressure in chamber/camera (Fig. 17-3b). After intermediate contact 7 will reach the backstop, it is stopped, and since contact 14 continues motion downward, then between contacts 7 and 14 appears the second arc (extinguished), around which also are formed the gases.

Simultaneously through tubular slide contact 14 is opened/disclosed the communication/report to internal cavity of chamber with switch tank. Under effect of pressure, created in chamber/camera with the gas-generating arc, the gases, which are formed around the quenched an arc, are fixed through the hollow slide contact into switch tank. The flow of gas involves/tightens arc inside tubular contact. Appears longitudinal blast, as shown in Fig. 17-3c.

Due to the pressure, supported in chamber/camera by the gas-generating arc, oil always strives it will approach the arc, as a result of which around the quenched an arc occurs violent gas generation which through the tubular contact are rejected into switch tank. By all this is caused the intense deionization of arc.

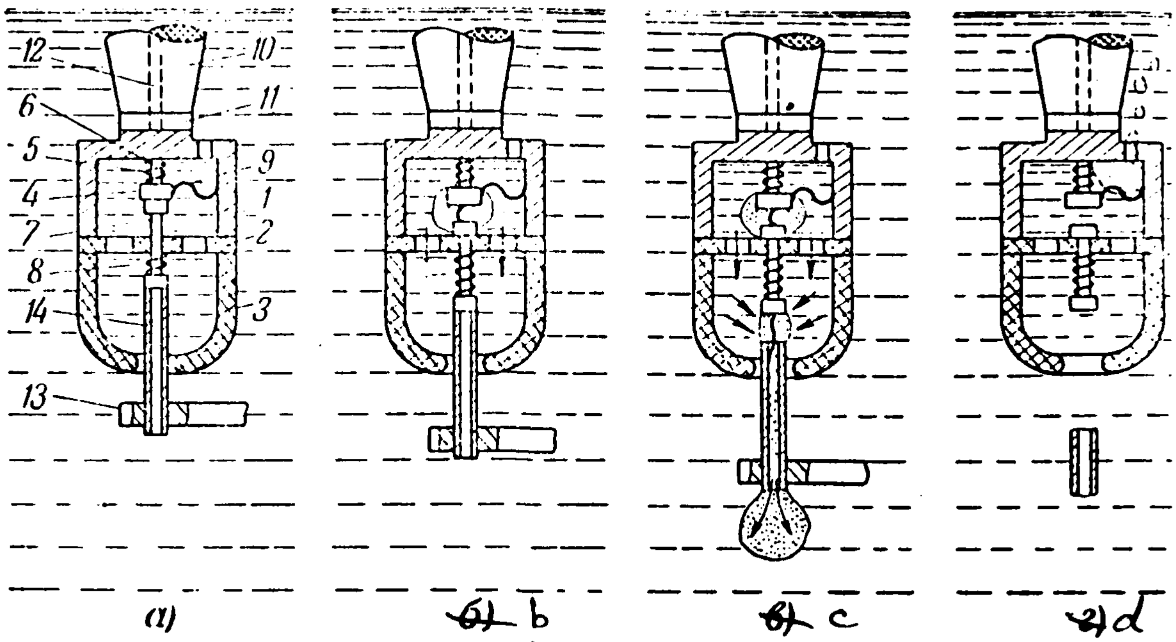

Fig. 17-3. Arc-suppression chamber/camera of the longitudinal oil blast of oil breakers of the type MKP (old series).

a) is connected; b and c) the process of the cutoff/disconnection; d) is disconnected.

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At the moment of transiting the current through zero arcs in chamber/camera they go out, the generation of gas ceases, pressure in chamber/camera and rate of gas blast sharply decrease. For the same so that the arc again was not ignited, it is necessary, as this has

already been indicated, precisely, to at this time ensure this intense deionization of arc gap so that the rate of an increase in its dielectric strength would be above voltage recovery rate on the contacts of switch. In the chambers/cameras in question for guaranteeing this condition with the small course of contact 7 is necessary sufficiently high pressure in them up to the moment/torque of disagreeing contacts 7 and 14.

With the cutoff/disconnection of the current, equal to the rated current of the cutoff/disconnection of switch, the pressure indicated comprises order 40-50 atm(tech). In this case the arc usually goes, and whereas the process of cutoff/disconnection concludes upon first transfer of the current through zero after the formation of the arc between contacts 7 and 14. Let us note that the pressure in switch tank does not exceed 5-10 atm(tech).

It is logical that with the cutoff/disconnection of low currents the pressure in chamber/camera and the rate of the flow of gases will be considerably less, as a result of which the arc extinction is involved/tightened and it frequently finally goes out only after the output of slide contact 14 of the chamber/camera, i.e. with the sufficiently large distance between contacts 7 and 14.

Thus, in chamber operation with longitudinal blast are two

periods: preparatory when in chamber/camera is created the necessary pressure, and the second period - strictly arc extinction. It is logical that the preparatory operating cycle of chamber/camera increases the tripping time of switch. Furthermore, the switches of old series MKP had the insufficiently ideal construction/design of movable mechanism. As a result, this disconnection time of these switches was up to 0.15-0.20 s or even more in all, i.e., they were not high-speed.

The disconnecting ability of the switches of old series was relatively small - it did not exceed 2500 MVA. In such a manner, both on action time and according to the disconnecting ability these switches did not satisfy working conditions in contemporary powerful/thick power systems.

Fig. 17-4 in the form of an example shows the cross section of one phase of an oil breaker of the type MKP-274 to 600 A and 220 kV, equipped with examined arc-suppression chambers/cameras 10. Switch has oil-filled condenser/capacitor wall entrance insulators 3, on which are established/installed current transformers 5 and device for measuring voltage 6 (see §20-4). On the day of the tank is oil buffer device/equipment 11, into which is struck the face of contact crosshead 8 at the end of the course of cutoff/disconnection. Buffer device/equipment absorbs kinetic energy of the moving elements of the

switch and deadens the shocks, experience/tested by switch at the end of the cutoff/disconnection when moving elements must stop. All switches have oil or spring buffers.

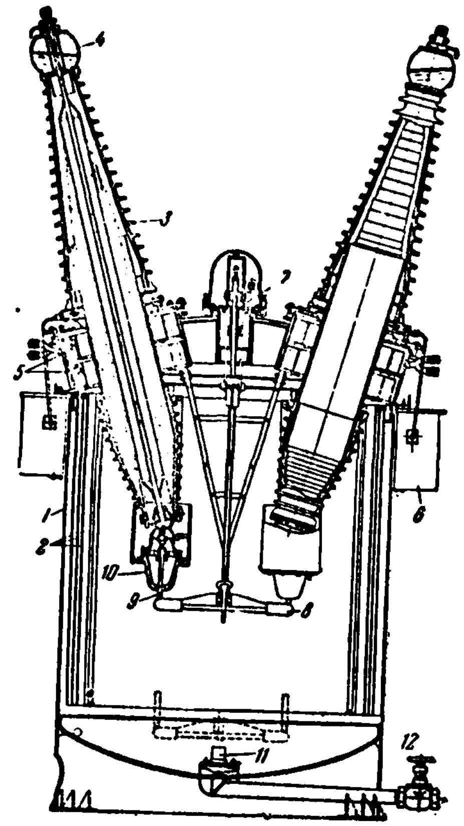

Fig. 17-4. An oil breaker of the type MKP-274 on 220 kV, 600 A, 2500 MVA (one phase).

1 - tank; 2 - insulation of the tank; 3 - porcelain oil-filled wall entrance insulator with the supplementary condenser/capacitor insulation of the current-carrying rod; 4 - glass expander of the insulator; 5 - built-in current transformers; 6 - device for measuring the voltage (PIN); 7 - drive mechanism; 8 - contact crosshead; 9 - the slide contact; 10 - arc-suppression

chamber/camera; 11 - the oil dashpot; 12 - oil-release valve/gate.

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At present Soviet plants release the series of new multi-volumetric oil breakers of the type MKP with the chambers/cameras of the transverse oil blast: on 35 kV of the type MKP-35, on 110 kV - MKP-110, on 220 kV - MKP-220. They all three-tank and are intended for external installation.

Switches to voltage 35 kV of the type MKP-35 have arc-extinguishing chambers/cameras of transverse oil to blow itself with one disruption. The schematic of device/equipment and the principle of arc extinction in such chambers/cameras are shown on Fig. 17-5 (chambers/cameras are established/installed in each disruption of switch).

In metal housing 1 (to 600 A - steel, to 1000 A - brass or bronze) is established/installed end-type contact 2 whose construction/design is analogous the construction/design of the end-type contact of the dismantled/selected chamber/camera with longitudinal oil blast. The lower part of the chamber/camera is collected from the insulating plates of 4 special forms, which form two transverse slots (channel) 5. In the connected position of switch

(Fig. 17-5a) these slots are overlapped by the body of movable contact bar 3.

In the beginning of the process of the cutoff/disconnection of switch the arc between contacts 2 and 3 burns in the upper part of the chamber/camera and pressure in it rapidly increases. During further motion of slide contact 3 are downward alternately opened/disclosed transverse slots 5 and appear transverse blast, energetically deionizing arc.

In this chamber/camera and in all other chambers/cameras of the oil breakers in which the pressure is created by the gases, generated by arc itself, pressure in chamber/camera and rate of transverse gas flow depend on arcs current. At the moment of transiting the current through zero, when arc goes out, pressure in chamber/camera descends and the rate of the flow of gases decreases. But precisely at this moment it is important to support energetic blast for achievement of the large recovery rate of dielectric strength of the gap/interval between contacts.

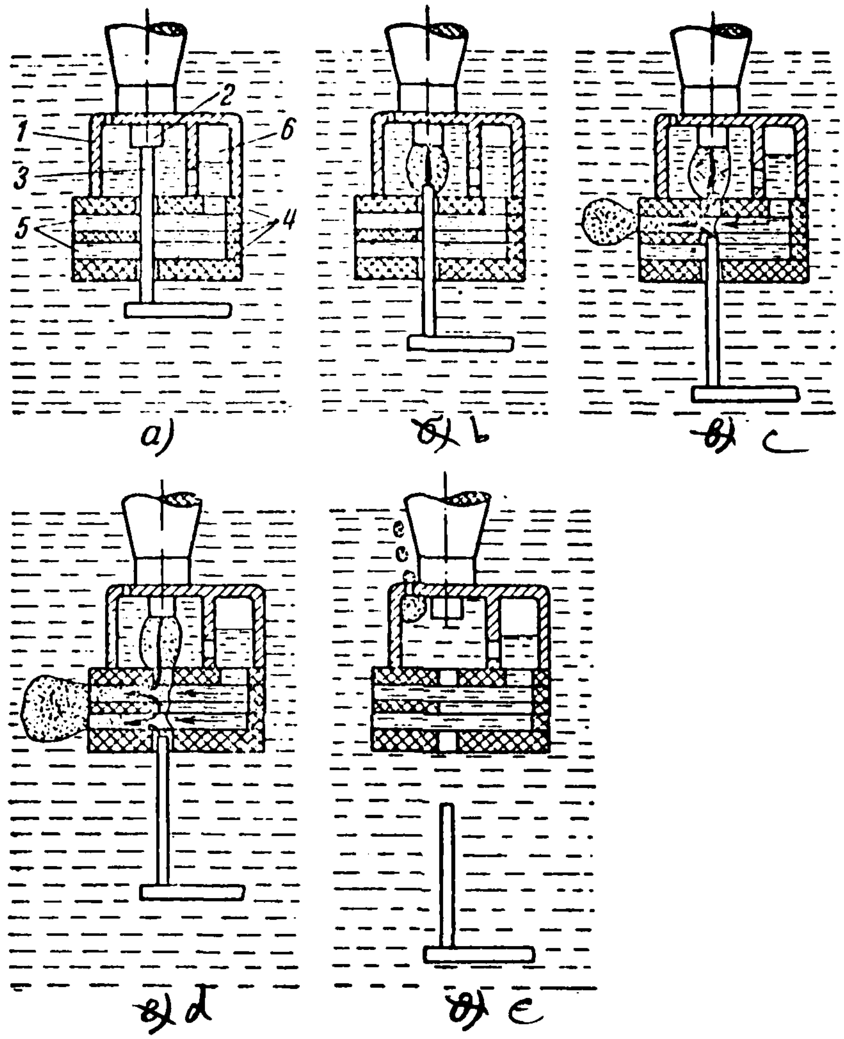

Fig. 17-5. Arc-suppression chamber/camera of the transverse oil blast of a switch of the type MKP-35.

a) is connected; b, c and d) the process of cutoff/disconnection, e) is disconnected.

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For providing this in many chambers/cameras of contemporary oil breakers, as in that examined/considered, are created the filled with air buffer spaces.

In chamber/camera in Fig. 17-5 this buffer space 6 is provided in the right side of the chamber/camera. With the filling of switch oil in this space remains airspace.

In the initial stage of cutoff/disconnection, i.e. before the discovery/opening of blast slots or channels 5, the air in buffer space is presssed (accumulation of energy). It is logical that therefore at the moment of the maximum of arcs current the pressure on chamber walls somewhat decreases (part of oil overflows into buffer space).

At the moment of the discovery/opening slots 5 and onset to blow the pressure in chamber/camera descends especially considerably, when arcs current is close to zero (decreases the generation of gas). But simultaneously with this the air, compressed in buffer space, begins to be expanded and, operating as the piston (as certain supplementary

energy source), supports the blast, which deionizes arc gap.

The general view of oil switch of the type MKP-35 is shown in Fig. 17-6.

In the oil breakers of new series in voltages 110 and 220 kV are used the arc-suppression chambers/cameras of transverse oil blast with multiple break. Let us examine device/equipment and the work of an oil breaker of the type MKP-110 M. Fig. 11-7 schematically shows chamber/camera, while in Fig. 17-8 the cross section of the phase of this switch where is visible the installation of chambers/cameras.

Chamber casing is carried out in the form of cylinder 5 of insulation (Fig. 17-7a), equipped from above by ring 7, and from below with disk 8 of brass. Ring 7 is connected with bronze holder 4, with the aid of which the chamber/camera is attached to the cap/hood of 2 wall entrance insulators 1. The current-carrying rod 3 of the latter is electrically connected with holder 4 and ring 7. To the internal surface of chamber/camera are fastened/strengthened motionless copper contacts 9-10-11-12. In pairs contact 9 with ring 7, contacts 10 and 11 and contact 12 with disk 8 are connected by copper rods 13-14-15. Rods 14 and 15 are closed with textolite plates 16 and 17 for preventing the overlap on them of arc from slide contacts 18 and 19 with the cutoff/disconnection of switch (Fig.

17-7b).

Two-way slide contacts 18 and 19 are put on to bakelite rod 22 whose position along the axis of chamber/camera is provided with the fact that it is passed through openings/apertures in the bottom of holder 4 and in the disk of 8 housings. Springs 20 and 21 serve for the creation of the necessary pressure in contact.

At the butt end of rod 22 is attached brass contact 23, connected by flexible stranded wire 25 with disk 8.

In the connected position of the switch of crosspiece 27 occupies end upper position, and its slide contact 26, being located within metallic beaker 28, wrings out upward entire movable system of chamber/camera which occupies the position, depicted in Fig. 17-7a (springs 20, 21 and 24 are compressed).

Each chamber/camera is equipped with the shunting effective resistance to r=750 ohms, connected to ring 7 and disk of 8 chambers/cameras. Resistor/resistance is made from the Nichrome spiral, packed in the grooves of bakelite cylinder and prisoner into the second shielding bakelite cylinder with openings/apertures on its surface for the passage of oil. Cylinders with backs-out resistor are fastened/strengthened to arc-suppression chambers/cameras (Fig.

17-8).

With the connected switch through the shunting resistors/resistances the current does not flow/occur/last, since they are shortened/shorted out by the locked contacts of the chambers/cameras of switch (Fig. 17-7). In process the cutoffs/disconnections of the switch of resistance R prove to be connected in parallel to chambers/cameras, i.e. they shunt them, thanks to which the voltage, applied to the phase of switch, is distributed approximately/exemplarily equally between the chambers/cameras (see §13-2).

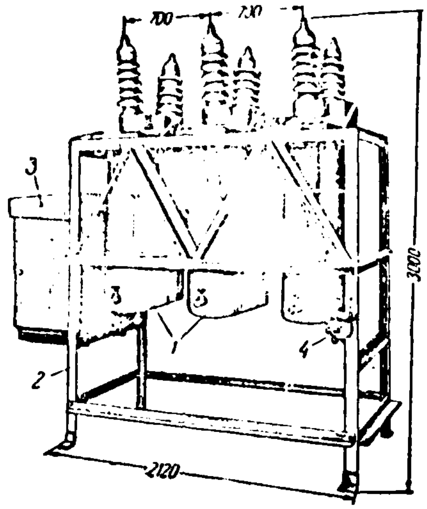

Fig. 17-6. An oil breaker of the type MKP-35 on 35 kV, 600 A, 750 MVA.

1 - oval tanks; 2 - steel frame; 3 - drive; 4 - hoist for the settling of tanks.

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With the cutoff/disconnection of the switch of pole arm 27 it is moved downward. Under spring effect 24 rod 22 is also moved downward. The first time contacts 23 and 26 move together. Are broken contacts within chamber/camera and between them appear four arcs, as shown in Fig. 17-7b. Arcs 31 and 32 are gas-generating and serve for creation in the chamber/camera of the necessary pressure. Arcs 29 and 30 are extinguished, they appear against openings/apertures 6 in chamber casing.

gas generating arcs ~~Gazogeneriruh5/e dugi~~ 31 and 32 create in chamber/camera the pressure in several ten atmospheres, under action of which quenched an arc 29 and 30 are blown out by the gases through exhaust opening 6 into switch tank (Fig. 17-7b).

In these chambers/cameras the quenched an arc undergo blowing immediately after their formation/education, i.e., in them there is no expenditure of time for the preliminary creation of pressure as this it was in chambers/cameras with longitudinal oil blast. Arc

extinction is facilitated also because of multiple break of the circuit: in all to phase (in two chambers/cameras) has the place of eight disruptions, moreover the arc gaps of four disruptions are energetically deionized by the cross flow of gas. They substantially facilitate arc extinction, especially with the cutoff/disconnection of low currents, backs-out resistor of r against clusters of which it was indicated in chapter 13.

As a result of entire this time of arc extinction in switches with the chambers/cameras of transverse oil blast in question it is small and usually it does not exceed two-three half-periods (0.02-0.03 s).

After arcs in chambers/cameras went out, through backs-out resistor continues to flow/occur/last small current I_r (accompanying current). As soon as contact system of chamber/camera it will reach the backstop and will stop, contacts 23 and 26 are radiated and will break current I_r Since this current is small, then appearing between contacts 23 and 26 arcs easily are extinguished without the use/application of any arc-suppression devices/equipment (Fig. 17-7c). Position with completely off switch is shown in Fig. 17-7d.

To motionless and slide contacts are welded arc-resistant caps

(plates) from the cermet connection, which consists of copper and tungsten.

The general view of an oil breaker of the type MKP-110M on 110 kV and 600 A is shown in Fig. 17-9.

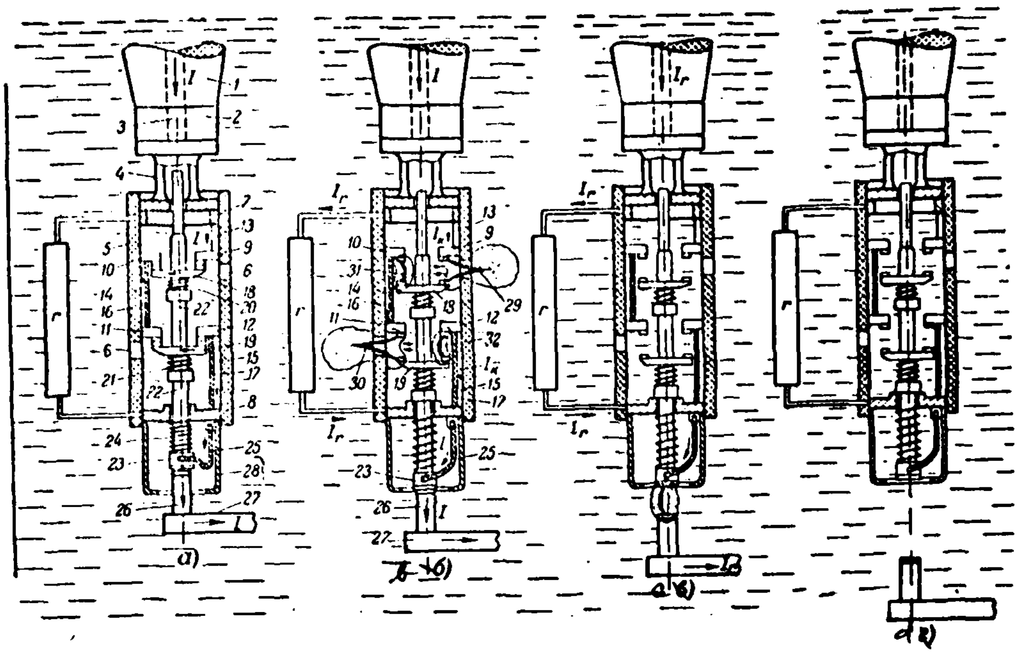

Fig. 17.7. Arc-suppression chamber/camera of the transverse oil blast of an oil breaker of the type MPK-110M on 110 kV. a) is connected; b and c) the process of the cutoff/disconnection; d) is disconnected.

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Oil breakers of the type MKP-220 kV have large overall sizes and somewhat different construction/design of arc-suppression chamber/camera (Fig. 17-10). In the latter there are six gaps, between which with cutoff/disconnection appear three gas-generating and three quenched an arc, and also auxiliary oil-injection

device/equipment, which, in the first place, after the termination of arc extinction rapidly drives out from chamber/camera the decomposition products of oil and accelerates the filling with its fresh oil and, in the second place, it provides reliable arc extinction with the cutoff/disconnection of low currents. We will be restricted to the examination only of the auxiliary oil-injection device/equipment, since in other respects the equipment and the chamber operation are clear of the description presented earlier of the chamber/camera of a switch of the type MKP-110M.

In holder 1 is pressed the cylinder 2 of oil-injection piston 3. With off switch under spring effect 7 piston is located in lower position, as shown in Fig. 17-10. In this position the internal cavity of chamber/camera freely is communicated with the space of switch tank through two series/rows of openings/apertures 4 and 5 in the walls of cylinder 2.

Upon the start of switch rod 6 is moved upward and simultaneously with slide contacts 10 it is upward moved and piston 3, pressing arranged/located above it spring 7. In the connected position the piston closes openings/apertures 4, thanks to which the internal cavity of chamber/camera proves to be isolated/insulated from switch tank.

With the cutoff/disconnection of switch rod 6 with slide contacts 10 begins to be moved downward. Simultaneously under spring effect 7 begins to be moved downward piston 3. If switch disconnects relatively larger current, then as soon as contacts 10 and 11 they are radiated, and between them will arise arc, pressure in chamber/camera sharply grows/rises also under its action piston 3 begins to move conversely upward to backstop 8, i.e., it is higher than its normal position with the connected switch. Springs 7 and 9 are pressed.

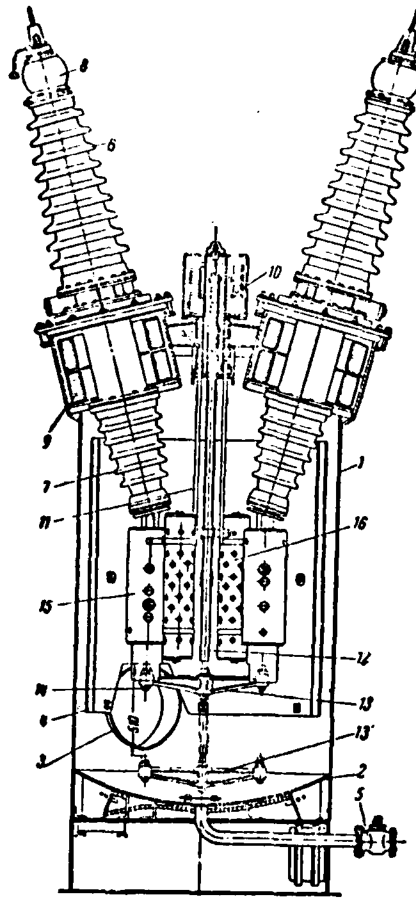

Fig. 17-8. An oil breaker of the type MKP-110M on 110 kV, 600 A, 3500 MVA (one phase). 1 - tank; 2 - bottom of the tank; 3 - access; 4 - insulation of the tank; 5 - oil-drain valves; 6 and 7 - upper and lower parts of wall entrance insulator; 8 - glass expander; 9 - built-in current transformers; 10 - drive mechanism; 11 - guide; 12 - insulating rod; 13 - contact crosshead (13') - position is

disconnected); 14 - the slide contacts; 15 - the explosion chambers; 16 - backs-out resistor in insulating cylinders.

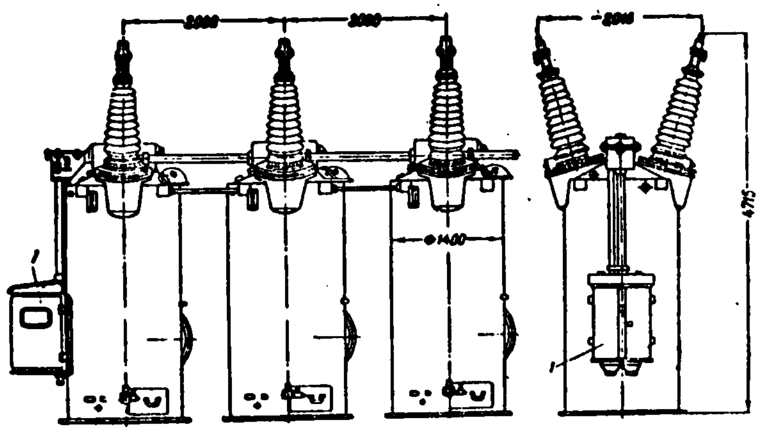

Fig. 17-9. An oil breaker of the type MKP-110, on 110 kV, 600 A, 3500 MVA.

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Under high-pressure action in chamber/camera is created the energetic transverse blast through three series/rows of slots 16, which leads to rapid arc extinction. After this pressure in chamber/camera it descends and therefore piston 3 under the action of compressed springs 7 and 9 is rapidly moved downward, displacing from chamber/camera the remaining in it gases and accelerating the filling with its oil (chamber/camera blows itself by fresh oil). Therefore the chamber/camera rapidly prepares for reclosing.

Somewhat otherwise chamber/camera works with the

cutoff/disconnection of comparatively low currents. In this case the pressure in chamber/camera, caused by the generation of gas by the arcs of gaps, proves to be small and insufficient for a rapid arc extinction. It proves to be insufficient also in order to delay the motion downward of piston 3. The latter under spring effect 7 continues to be moved downward and pressure oil into the region of arcing. That appearing with this transverse blast proves to be sufficient for a reliable arc extinction with the small disconnected current.

Thus, with the cutoff/disconnection of relatively low currents arc is extinguished not due to the pressure, created with arc itself, but by the forced flow of oil, created mechanically with piston stroke 3 under spring effect 7.

Backs-out resistor these chambers/cameras do not have [17-1, appendix I, written by A. M. Bronstein].

Because of the short time of the arc extinction and improved construction/design of movable mechanism the tripping time of the switches MKP of new series comprises order 0.08 s, i.e., they are high speed.

The nominal power of the cutoff/disconnection of these switches

reaches 5000 MVA (table P-14). Soon will be begun the production of switches of the type MKP-220 to the nominal power of cutoff/disconnection 7000 MVA.

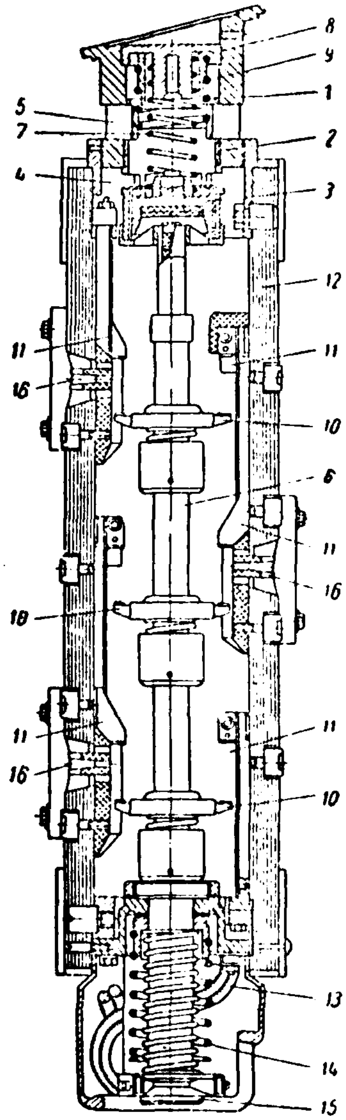

Fig. 17.10. Arc-suppression chamber/camera of an oil breaker of the type BKP-220 on 220 kV. 1 - holder; 2 - cylinder; 3 - piston; 4 and 5 **- opening/aperture; 6 - rod; 7 - spring; 8 - backstop; 9 -** auxiliary

spring; 10 - the slide contacts; 11 - the fixed contacts; 12 - housing of the chamber/camera; 13 - flexible connections; 14 - spring; 15 - external contact; 16 - exhaust slots.

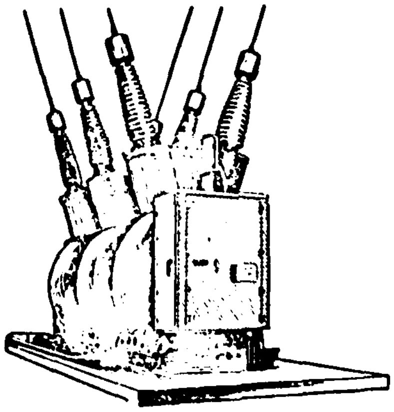

Fig. 17-11. Oil breaker on 230 kV, 10000 MVA.

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Are developed/processed even more powerful/thick switches, also, to large voltages.

The phases of the switches of types MKP-110 and MKP-220 can be connected mechanically and be controlled with common drive (1 in Fig. 17-9), i.e., have three-phase control. But if we the phases of these switches do not connect mechanically and to supply with independent drives, then it is possible to carry out phase-by-phase control of switch. In this case of phase prove to be connected only with electrical diagram the controls of three drives.

In recent years some foreign firms attained the considerable successes in the production of multi-volumetric oil breakers with multi-disruptive arc-suppression chambers/cameras.

In the form of an example Fig. 17-11 and 17-12 give general view and section/cut of one phase of the oil bulk-oil breakers, manufactured with one American firm to nominal voltages to 330 kV inclusively and at the power of cutoff/disconnection to 25,000 MVA. Switches have tanks of original construction (lens-shaped form), with which is provided their high mechanical strength with the considerable decrease of total weight and weight of oil, in comparison with usual cylindrical tanks. So, if Soviet oil breaker in three cylindrical tanks of the type MKP-220 at the power of cutoff/disconnection 5,000 MVA has the total weight of three phases 90 t with the weight of oil 48 t, then the shown in Fig. 17-11 switch on 230 kV at the power of cutoff/disconnection 10,000 MVA has the total weight of three phases of approximately/exemplarily 36 t with the weight of oil a total of of approximately 16 t.

The arc-suppression chamber/camera of these switches has a cylinder with piston and spring. Upon the start of switch finger/pin 10 on pole arm 8 (Fig. 17-12) enters inside chamber/camera 4 and, pressing on the stock/rod of the piston indicated, is risen it upward; the spring of piston it is presssed. With the

cutoff/disconnection of the low currents when the pressure in chamber/camera, caused by the generation of gas by arc, proves to be small and insufficient for a rapid arc extinction, piston under the action of the compressed spring is moved downward and pressure oil into the region of arcing, that also provides its rapid extinction.

In the case of the cutoff/disconnection of comparatively high currents, when the gas pressure in chamber/camera is great, the valve of the cylinder of the oil-injection piston is closed and arc is extinguished, as usual, by the cross flow of gas. After the termination of arc extinction the oil-injection piston blows chamber/camera by fresh oil, as this was indicated above, in the examination of the chamber/camera of a switch of the type MKP-220. The similar oil-injection pistons are applied in the arc-suppression chambers/cameras and other switches, foreign firms [17-1 and 17-2].

The tripping time of similar switches comprises order 0.05-0.06 s.

Multi-volumetric oil breakers with longitudinal-slotted chambers/cameras (horseshoe chambers/cameras; deionization gratings).

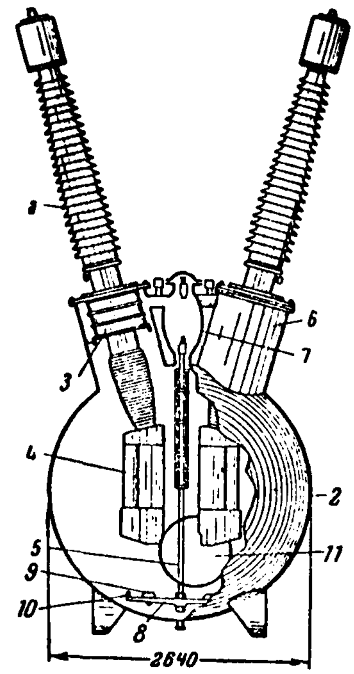

Fig. 17-12. Oil breaker on 330 kV, 15000 MVA (one phase). 1 - wall entrance insulator; 2 - tank; 3 - built-in current transformers; 4 - arc-suppressing chamber/camera; 5 - insulating rod; 6 - jacket of current transformers; 7 - jacket of the drive mechanism; 8 - contact crosshead; 9 - the slide contact; 10 - finger/pin for the shift of oil-injection piston of chamber/camera.

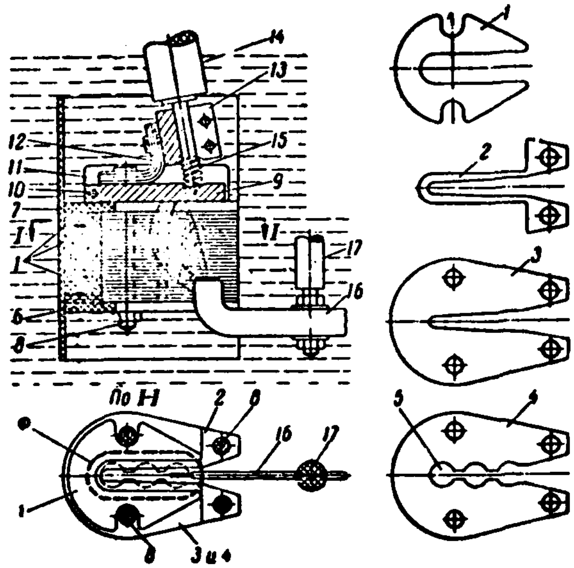

Fig. 17-13. Longitudinal-slotted chamber/camera of oil breaker. 1, 2, 3, and 4 - plates from which is comprised the chamber/camera.

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Longitudinal-slotted chamber/camera consists of several packets each of which is comprised of one the steel and several insulating plates of the horseshoe form (Fig. 17-13), packed in the following order; inside steel plate 1 is inserted insert 2, intended for the isolation of steel plate from slot, then to steel plate is superimposed one insulating plate 3, further several insulating plates 4 and finally one additional plate 3.

On top and bottom of such several combined packets are superimposed thick plywood plates 6 and 7, also cut-away. With the aid of pins 8 of insulation these packets are tightly tightened and attached to metallic holder 11, fastened/strengthened with the aid of clamp 13 to the current-carrying rod of wall entrance insulator 14.

Because of semicircular grooves 5 in plates 4 on the internal surface of the narrow slot of chamber/camera are formed the deepenings (pockets).

Motionless area contact 9 is fastened/strengthened to axis 10, passing through the lateral struts of holder 11, and it is connected by flexible current-carrying connections/communications 12 with clamp 13.

Slide contact is carried out in the form of flat/plane knife 16 with the bent back upward ends/leads and is suspended/hung from insulating rod 17.

Spring 15 provides the necessary pressure in contact and deadens the shocks upon start.

Chambers/cameras are installed in each gap of switch.

During interrupting of contacts the arc appears in the beginning of the slot of chamber/camera. Forming around arc magnetic flux Φ is closed through steel plates and air gap, as shown by heavy dotted line in Fig. 17-13. Striving to be shortened, magnetic lines of force rapidly involve/tighten arc inside slot. The latter is filled with oil; therefore during the motion of arc inside slot oil violently evaporates and is decomposed/expanded. If moreover, some plates, for example 2 and 4, are made from fiber, then the latter with contact with arc partially is decomposed/expanded, separating/liberating a large quantity of gases (hydrogen, carbon dioxide, water vapor). All this is accompanied by a sharp increase in the pressure within slot and by the intense flow of gases in the zone of arc, as a result of which the arc energetically is cooled and deionized. The deionization of arc is amplified also as a result of its contact in slot with the surface of solid dielectric.

Part of the gas under pressure is wrung out into deepenings within the slots, formed by semicircular grooves 5 in plates 4. When arcs current crosses the zero value, pressure in the zone of arc falls and gas from the deepenings of slot escapes into switch tank, producing the energetic deionization of arc gap.

With insufficient distance between contacts the arc ignites repeatedly. Finally arc usually goes out through several half-periods after the disagreement of contacts. The tripping time of switches with similar explosion chambers is 0.1-0.15 s.

Longitudinal-slotted chambers/cameras great use/application obtained in multi-volumetric oil breakers to voltage 35 kV. Soviet plants manufacture with similar chambers/cameras oil breaker to voltage 35 kV of the type VM-35 in nominal power of cutoff/disconnection 400 MVA. the section/cut of the phase of this switch is given in Fig. 17-14. Switch three-tank, for external installation. The appearance it much the same, as a switch of the type MKP-35, shown in Fig. 17-6.

17.3. Oil breakers with small space of oil.

General information. In small volume oil breakers oil is utilized only for an arc extinction; therefore a quantity of oil in them is accepted smallest possible from the condition for arc extinction, and the insulation of current-carrying parts is realized with the aid of air and ceramic or organic insulation.

The weight of oil in small volume oil breakers many times is less than in multi-volumetric ones. For example, in multi-volumetric

oil breakers to 10 kV and nominal power of cutoff/disconnection 250 MVA the weight of oil 250 kg, while in small volume switches to the same parameters the weight of oil is only 10 kg.

Because of small space of oil and very rugged construction of tanks small volume switches can be considered explosion- and flame-resistant. This fact increases the safety of servicing switches and considerably simplifies their installation in the closed distributors.

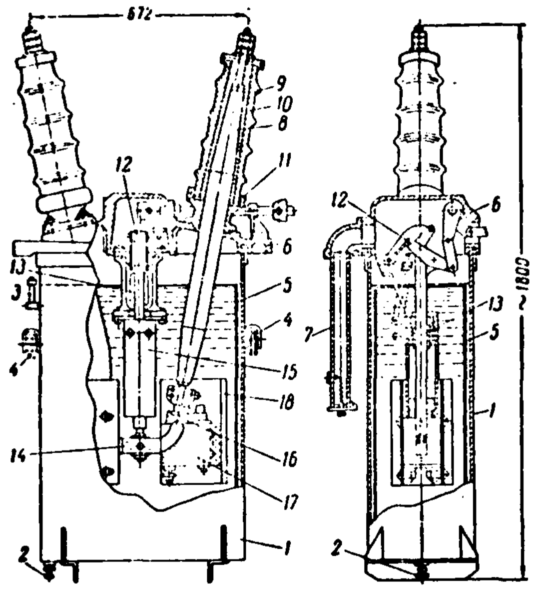

Fig. 17-14. An oil breaker of the type VM-35 on 35 kV, 600 a, 400 MVA (one phase). 1 - tank; 2 - oil-drain valve; 3 - oil gauge; 4 - rollers for the cables; 5 - insulating facing; 6 - cover/cap; 7 - gas bleeder; 8 - bakelite insulator; 9 - porcelain cover; 10 - insulating compound; 11 - collar of the insulator; 12 - drive mechanism; 13 - rod; 14 - slide contact; 15 - bakelite beaker; 16 - not slide contact; 17 - arc-suppression chamber/camera; 18 - screen.

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In all small volume oil breakers there are arc-suppression chambers/cameras, most frequently with transverse blast. Depending on

the voltage and power from voltage and power of cutoff/disconnection the switches have one or several gaps in phase.

Small volume oil breakers can be constructed to all voltages for internal and external installations and to the very large power of cutoff/disconnection. Soviet plants manufacture them to voltages to 110 kV inclusively.

Low-volume oil breakers to voltages to 20 kV inclusively have one or two gaps in phase. Each gap of switch is supplied with separate tank with the built-in arc-suppression device/equipment. Thus, switch with one gap in phase has three tanks, and switch double-break in phase - six tanks (on two to phase).

Tanks can be made from boiler steel (welded) or from insulation, which possesses necessary mechanical and dielectric strength.

In the case of metallic tanks the current-carrying busbars connect directly to the heads of tanks or to tanks themselves; therefore the latter are located under voltage and are not grounded as the tanks of multi-volumetric oil breakers.

In all cases the tanks of small volume switches are fastened to the porcelain stand-off insulators, which reliably insulate them from

the grounded frame of switch.

Oil breakers with one tank to phase (three-tank). Wide application in Soviet installations by voltage to 10 kV inclusively found switches of the VMG-133 type (switch oil pot) to nominal voltage 10 kV, rated currents of up to 1000a inclusively and power cutoffs/disconnections 350 MVA. Switches have comparatively small overall sizes, weight and cost/value, they are intended for vertical installation on walls and metal constructions of the closed distributors.

Let us become acquainted with equipment and work of switches of the type VMG ~~MVG~~-133 (Fig. 17-15). The metallic tanks of 1 these switches are located under voltage, since the busbars of distributor connect up bolt terminals/grippers 9 on their bottoms; therefore each tank is attached on two stand-off insulators 2, established/installed on overall steel frame 11. Within tank, to its bottom, is fastened/strengthened the motionless socket contact (see also Fig. 17-16). Movable contact bar 4 passes through insulator as 3 to the head of tank. On the shaft of 10 switches are welded three double-armed levers 12, to long arms of which by means of porcelain rods 6 are suspended/hung the contact bars of 4 three phases. Rods 6 are hinged connected with levers 12 and rods 4.

To the cap/hood of wall entrance insulator 3 is

fastened/strengthened steel clamp by 7 with terminal/gripper 8 for connection of busbars. Terminal/gripper 8 is electrically connected with movable contact bar 4 by aid of copper flexible member 5.

Path of current in the connected position of the switch: clamp 9, socket contact on the bottom of tank, rod 4, flexible member 5, terminal/gripper 8. To each phase there is one pair of contacts, which perform the role of workers and arc-suppression.

Switch tanks to rated current 600 a steel. Since in the connected position of switch current flows/occurs/lasts over contact bar 4, then created with this current magnetic flux is closed on the walls of tank.

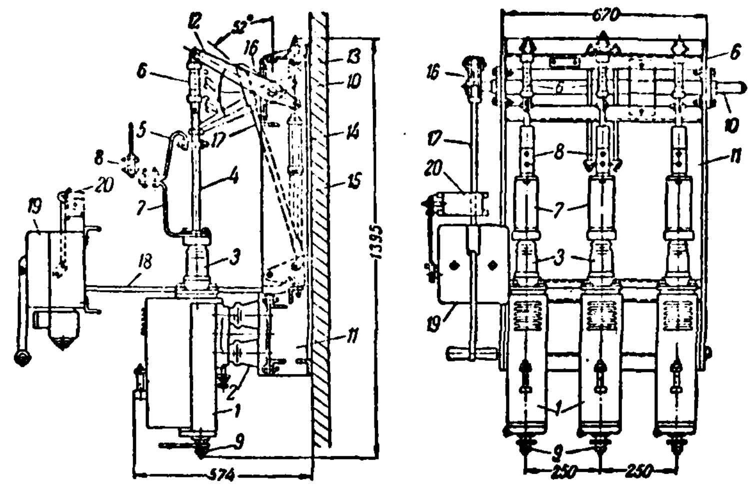

Fig. 17-15. An oil breaker of the type VMG-133 on 10 kV, 600 a, 350 MVA.

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For decreasing heating tank by eddy currents and as a result of hysteresis the vertical weld of tank (on the generatrix of cylinder) is welded by brass for an increase of the reluctance and decrease of induction in steel. In switches on 1000 a the tanks are fulfilled from brass, bottom from red copper, and head and caps/hoods of wall entrance insulators from non-magnetic cast iron. switch tanks possess large mechanical strength and are capable of maintaining/withstanding the pressure, which considerably exceeds the pressure, which appears in the process of cutoff/disconnection. The weight of oil in three

tanks is only 5-10 kg.

To the short arms of two outer levers 12 and to frame 11 are attached two disconnecting springs 15, stretched in the connected position of switch. Short lever arm of 12 average/mean phases at the end of the course of the inclusion rests into spring buffer 13, and at the end of the course of the cutoffs/disconnections - into oil dashpot 14, which serve for the softening of impacts with start and cutoff/disconnection.

On shaft 10 is established/installed rocker shaft arm 16, which with the aid of rods 17 and 18 is connected with hand drive 19. Can be used also electromagnetic actuator. Drive shaft is connected with the blocking-signal contacts 20 (chapter 16).

The section/cut of switch tank is given in Fig. 17-16. To base cylinder 1 is welded supplementary receptacle 6 of rectangular form which is communicated with the cylinder through ball valve 5. Valve makes it possible for oil to overflow from reservoir 6 into cylinder 1, so that the oil level in them identical. In the process of the cutoff/disconnection of pressure switch in the lower part of cylinder 1 is raised and valve 5 is closed.

Bakelite tube with 15 within insulator 14 is guide for contact

bar 13. Plug 4 serves for oil drain, while plug 10 - for the additional filling of oil.

Tank 1 is inside isolated/insulated by bakelite cylinders 2 and 3, which serve also for the attachment of arc-suppression chamber/camera 11. The latter is collected from several alternating plates from getinax and fiber. Between the plates of the lower part of the chamber/camera are three slots, located in different horizontal planes, which convert into uptakes 16, which emerge into the upper part of the tank (in section/cut Fig. 17-16 shows one slot and one uptake 16). In the connected position of switch (Fig. 17-17a) slide contact 13 overlaps the openings/apertures of the horizontal slots indicated.

To tank 1 is welded small steel chamber/camera 7, situated within supplementary reservoir 6 (Fig. 17-16). This chamber/camera is communicated with tank 1 through the rectangular opening/aperture, situated against the horizontal slots of explosion chamber. With the filling of tank with oil in chamber/camera 7 remains the filled with air buffer space.

The process of cutoff/disconnection occurs in the following order. During the motion of contact by 13 upward between it and socket contact 12 is formed the arc and pressure in the lower part of

the cylinder rapidly it is raised. The part of oil passes into chamber/camera 7, air in which is presssed. During further motion of contact 13 consecutively/serially are opened/disclosed slots of the chambers/cameras, through which is opened/disclosed the communication/report of the lower and upper parts of the chambers/cameras.

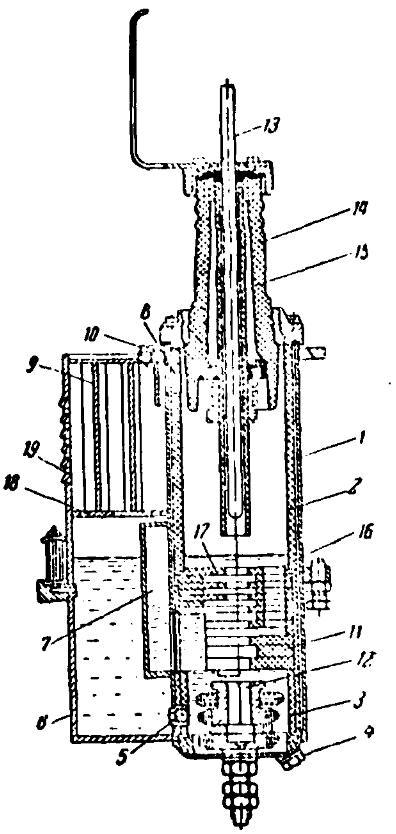

Fig. 17-16. Tank of an oil breaker of the type VMG-133 (off position).

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Appears the blast of gases and oil vapors in three different planes, which energetically deionizes arc (Fig. 17-17b). To arc extinction

contribute also the gases, isolated by fiber plates, and also intimate contact of arc with the surface of dielectric in the slots of chamber/camera.

On the role of buffer spaces in the work of arc-suppression devices/equipment it spoke above in § 17-2.

With the cutoff/disconnection of low currents the pressure in the lower part of the tank can be insufficient for the creation of effective blast in the slots of chamber/camera. In this case the arc is involved/tightened inside the central opening/aperture of chamber/camera, and into gaseous state passes oil, which is located in the pockets of 17 upper parts of the chamber/camera. After the output of slide contact from the central opening/aperture of chamber/camera the gases, which are located in the pockets indicated, create the supplementary longitudinal blast (Fig 17-17c), which ensures arc extinction.

In the upper part of tank 1 is rejected the mixture of gases and oil which through openings/apertures 8 (Fig. 17-16) enter labyrinth oil separator 9. Here oil settles on the partitions of separator and through openings/apertures 18 leaks off into the lower part of reservoir 6. The cooled and considerably deionized gases emerge outside through slots 19.

After the termination of cutoff/disconnection the oil level in reservoir 6 proves to be somewhat higher than in tank 1; therefore the part of oil overflows from the first the secondly through valve 5.

The space of oil in tank must be sufficient for an arc extinction. The datum level of oil is shown in Fig. 17-16. In the off position of switch the end/lead of slide contact must be located higher than the oil level, than is provided the gap between contacts in air, but not through oil which can be contaminated, since its space is small.

The same group of oil breakers includes Soviet oil breakers of the type VMP-6T (T - tropical performance) whose tanks are made from insulation. These switches are also intended only for internal installation, the parameters them approximately/exemplarily the same as switches of the type VMG-133 (table P-14).

The cylinders 1 of tanks of these switches are made from glass-epoxy with reinforced in them metallic collars 2, closed with heads 3. From above the cylinder of tank is established/installed metal housing 4, in which is placed the mechanism of slide contact.

Within tank on the head of collar is established/installed motionless socket contact. Above the latter is placed the three-slot explosion chamber of transverse blast, similar to the chamber/camera of a switch of the type VMG.

The mechanisms of slide contacts are connected with the shaft 5 of switches with insulating rods 6.

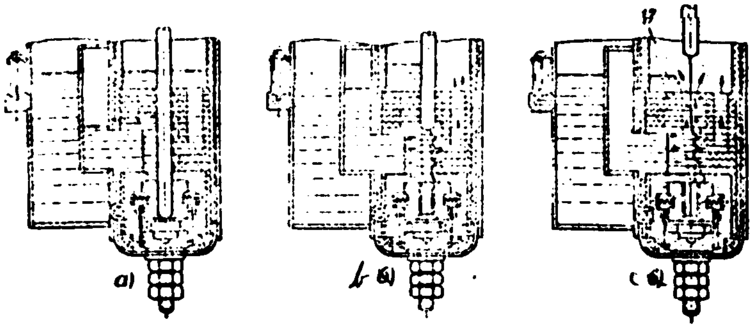

Fig. 17-17. Arc-suppression device/equipment of an oil breaker of the type VMG-133. a) is connected; b) the cutoff/disconnection of the high current; c) the cutoff/disconnection of low current.

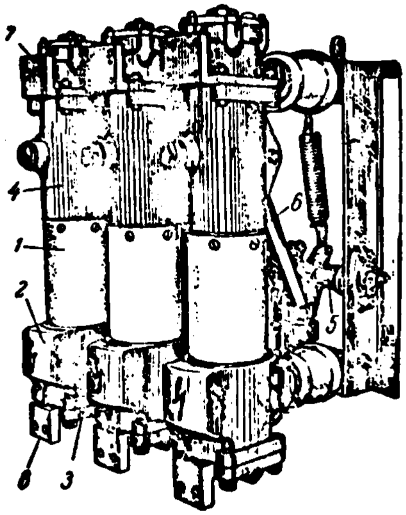

Fig. 17-18. Oil breaker of type VMP-6T on 10 kV, 1000 a, 350 MVA.

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For the connection of busbars serve terminals/grippers 7 and 8. Terminal/gripper 7 is connected with the movable contact bar through the roller collector shoe gear; therefore in these switches do not have flexible members of slide contacts as the switches of the type VMG (5 in Fig. 17-15).

In the upper part of housing 4 is placed the oil separator.

The upper ends/faces of the commutator bars of socket contacts and the ends/leads of the movable contact bars are equipped with soldering of the high-melting ceramic metal, which provides arc-resistance of contacts with the cutoff/disconnection of short-circuit currents.

Switches of the type VMP have smaller overall sizes and weight in comparison with switches of the type VMG; therefore during their use/application can be reduced the overall sizes of distributor. Especially large savings is reached at their use/application in cubic switchboard, the manufactured with plants in the form separate cabinets, supplied to mounting in the completely complete and assembled form (Vol. 2, chapter 9).

Oil breakers with two metallic tanks to phase (six-tank) received very wide acceptance in the electrical devices of large and average/mean power by voltage to 20 kV inclusively. All these switches are calculated for large rated currents - from 2000 A and more they are intended only for internal installation.

The representative of this group of oil breakers is a switch of the type MGG 229 (oil generator, pot), very propagated on powerful/thick Soviet electrical devices by voltage 6 and 10 kV. Schematic diagram on two tanks of one phase of this switch is given in Fig. 17-19. Since switch is calculated for large rated current, then on each gap are two pairs of the contacts: workers 4 and 5, placed in air, and arc-suppression 8 and 9, placed in tanks 1, oil-filled 13. Motionless make contacts 4 are carried out in the form of the contact knives, established/installed on the heads of tanks. Movable working finger contacts 5 (chapter 12, Fig. 12-12 or 12-13) are fastened/strengthened to the copper plate of 6' contact crossheads 6. working contact surfaces silver.

The motionless arc-suppression socket contacts (see also Fig. 17-20) are fastened/strengthened to the copperplated bottoms of tanks. Movable arcing contacts 9 are carried out in the form of rods and are fastened/strengthened to aluminum crosshead 6.

Contact 9 is isolated/insulated from the head of tank by wall entrance insulator 10.

Current-conducting busbars connect up contact corner irons 3 on the cast iron heads of 2 tanks. Tanks are established/installed on stand-off insulators 12.

In the connected position of switch (Fig. 17-19a) current flows/occurs/lasts mainly through the head of 2 tanks, make contacts 4 and 5 and copper plate 6' as this is shown by heavy line with rifleman/pointers. Through the arc-suppression outline (left terminal/gripper 3, head 2, tank 1, receptacle 8, rod 9, to pole arm 6, rod 9, receptacle 8, tank 1, head 2, right terminal/gripper 3) as that it is shown by thin lines, with rifleman/pointers, flows/occurs/lasts very insignificant current, since active and inductive reactances of this outline are considerably more than working outline.

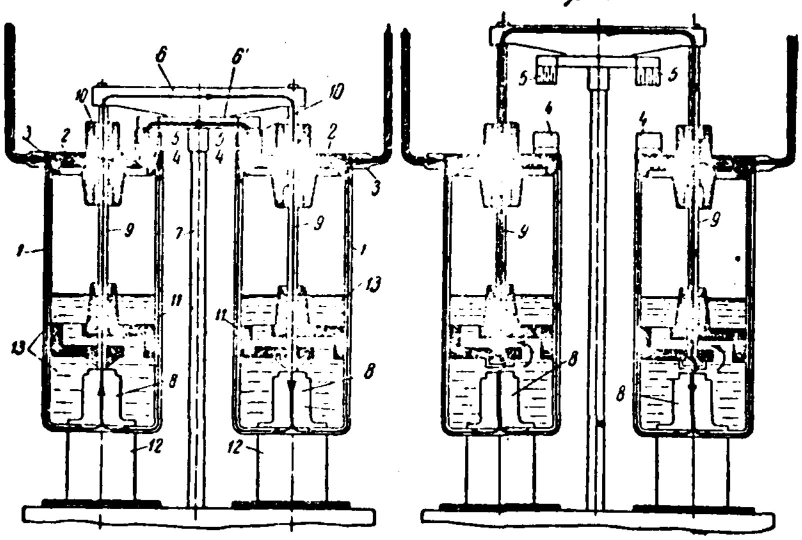

Fig. 17-19. Diagram of the course of current in oil breaker with small space of oil with two tanks to phase. a) the connected position; b) the process of cutoff/disconnection.

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Therefore the section of arcing contacts is small, since they are designed only for short-term flow of current with cutoff/disconnection.

With cutoff/disconnection (Fig. 17-19b) contact crosshead 6, fastened/strengthened to rod 7, is moved upward, in this case are

first broken make contacts 4 and 5 on both gaps and entire disconnected current is fixed through arc-suppression outline indicated above. Then are broken arcing contacts 8 and 9, between which is formed the electric arc.

For facilitating the arc extinction each switch tank is built in the chamber/camera of transverse oil blast 11, made from the boiled thoroughly in oil tree/wood and fixed to the head of tank with the aid of wooden struts with supplementary bakelite insulation (9 in Fig. 17-20). Through central opening/aperture is passed the movable rod, which in the connected position wrings out two brass shutters/valves, equipped with springs.

In the beginning of cutoff/disconnection the arc appears between the end/lead of the moving/driving upward rod and the motionless socket contact. During further motion of rod, i.e., along its output from the lower part of the tank, brass shutters/valves begin to flap and is formed the second arc between shutters/valves and end/lead of the rod (Fig. 17-21b). Transverse blast in average/mean channel is created due to the gas pressure in the lower part of the tank. The process of deionization and arc extinction proceeds in the manner that it was stated earlier.

With the cutoff/disconnection of high currents the pressure in

the lower part of the tank proves to be so considerable and transverse blast by such energetic that the arc finally goes out upon first or second transfer of the current through zero after the onset of transverse blast. In the case of diverging the low currents when pressure in the lower part of the tank is small, arc is involved/tightened into the opening/aperture of the upper neck of 4 chambers/cameras (Fig. 17-20 and 17-21) and as a result of considerable length it goes out.

In chamber/camera there are filled with air buffer spaces 15 (Fig. 17-20) whose role was presented earlier.

The space of oil in each tank (approximately/exemplarily 9 l) is determined by the conditions for arc extinction. Oil level must be such that in the off position between end/lead of the rod and oil there would be the sufficient air gap (reasons for this were shown in the examination of switches of the type VMG).

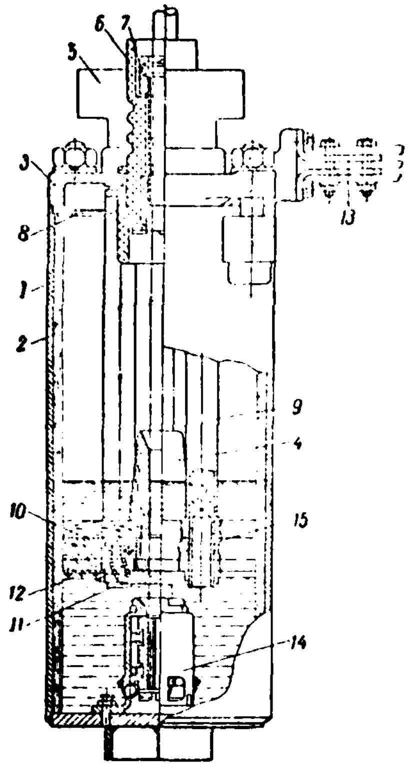

Fig. 17-20. Tank of an oil breaker of the type MGG 229. 1 - tank; 2 - insulation of the tank; 3 - head; 4 - plug; 5 - contact knife; 6 - wall entrance insulator; 7 - multiplexing the contact bar; 8 - oil seal; 9 - brace of the arc-suppression chamber/camera; 10 - chamber/camera; 11 - shutter/valve with the springs; 12 - leather cuff; 13 - contact corner irons; 14 - socket contact; 15 - buffer space.

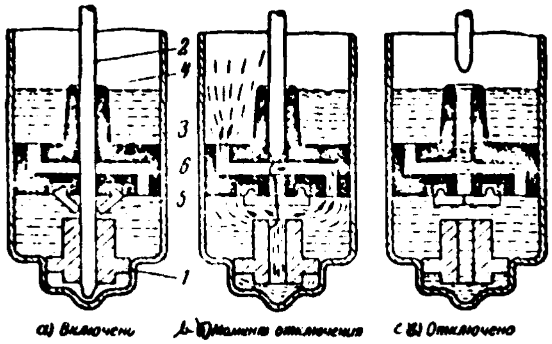

Fig. 17-21. Arc extinction in the chamber/camera of an oil breaker of the type MGG 229. 1 - motionless socket contact; 2 - the contact bar; 3 - chamber/camera of the transverse blast; 4 - neck; 5 - shutter/valve with springs.

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To avoid the overlap between the movable contact bar and the tank inside the latter is inserted the cylinder from electrical cardboard (Fig. 17-20).

After the onset of blast (Fig. 17-21b) into the upper part of the tank are blown out the decomposition products of oil. From tank 1 gases enter oil separator 9, available on each tank (Fig. 17-22). Oil separator (bakelite tube) is filled with porcelain balls/spheres. Heated and ionized gases, which contain a large quantity of hydrogen,

passing oil separator, are cooled and are deionized, and then through porcelain tube with 10 they enter gas-bleeding tube 11. Oil from oil separator leaks off back into tank. The gas vents of all tanks connect and derive/conclude outside distributor.

All six switch tanks are established/installed on overall steel frame 4. Since tanks are located under voltage, then from frame they are isolated/insulated by porcelain stand-off insulators 3. On each tank there is oil indicator tube with 2.

For decreasing the distance between the tanks of different phases and for the purpose of warning/prevention of the overlap between them are established/installed detachable insulating partitions 8.

In the upper part of the frame is fastened/strengthened general/common/total shaft by 6 with rocker shaft arm 7, disconnecting springs 5 and drive mechanisms of phases. Frame and gas vents ground.

At present plant "electrical device" manufactures six-tank switches with small space of oil of the type MG-10 (oil pot) to 10 kV, 5 kA and 1800 MVA and type MG-20 on 20 kV, 6 kA and 3000 MVA (Table P-14). These switches are the modernized constructions/designs

the previously manufactured switches of types MGG 229, MGG-529 and MGG-20. Switches of types MG-10 and MG-20 are characterized by from the previously released switches the more advanced construction/design of the series/row of parts. Because of the use/application of arc-suppression chambers/cameras of the improved construction/design is achieved/reached a somewhat larger disconnecting ability of new switches. General view of the switches of types MG-10 and MG-20 is shown in Fig. 17-22.

Essential deficiencies/lacks in the six-tank switches of the enumerated types are their large overall sizes and sufficiently considerable weight.

More compact and lung are manufactured with plant "Uralelektroapparat" six-tank oil breakers of the type MGG-10 on 10 kV, 2-3 kA and 500 MVA (Fig. 17-23). In these switches are used the described earlier tanks of oil breakers of the type VMG-133.

Tripping time of the switches of types VMG, MGG and MG is 0.1-0.2 s.

Small volume oil breakers to voltage 35 kV manufactures plant "electrical device" in two versions: type MG-35 for external installations and type MG-35V for internal installations (M - oil, G

- pot). Nominal power of the cutoff/disconnection of these switches 500 MVA.

Fig. 17-24 shows the general view of a switch of the type MG-35. Three phases of switch are mounted on overall welded frame 1, established/installed on two supports 2 of the sectional steel. Frame is grounded.

Within frame are arranged/located the crank mechanisms of the phases which are connected with general/common/total thrust/rod. The latter with the aid of hinged linkage is connected with the thrust/rod of electromagnetic actuator 3.

The mechanism of each phase with the insulating thrusts/rods is connected with the movable contact bar which with start and cutoff/disconnection of switch is moved within the insulating plug, closed with porcelain covers 4 and 5, fastened/strengthened to frame 1. From below lower cover 5 is fastened/strengthened arc-suppression chamber/camera 6, in which there is a fixed contact.

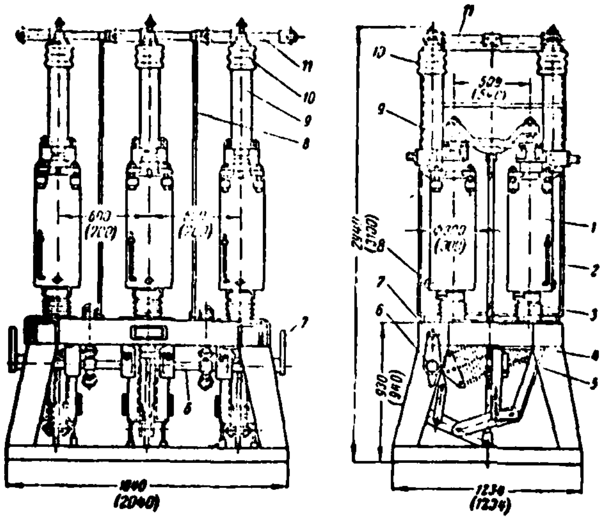

Fig. 17-22. An oil breaker of the type MG-10 (in brackets are shown the sizes/dimensions of a switch of the type MG-20).

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Gas-bleeding device/equipment 7, located in the top part below the cover 5. The oil level in spark extinguisher is monitored on oil indicator tube with 8, made from organic glass.

The busbars of distributor terminate 9 and 10. Terminal/gripper 9 by flex conductor is connected with upper end of the movable contact bar, which are located in metallic cap/hood 11. Terminal/gripper 10 is electrically connected with fixed contact in

arc-suppression chamber/camera. Path of current with the connected switch: terminal/gripper 9 - contact bar - fixed contact in chamber/camera 6 - terminal/gripper 10.

On each phase there are two built-in current transformers, put on to the plug, in which moves the contact bar, and with enclosed casing 12. As the primary winding of these current transformers serves movable contact bar. On jackets 12 are provided supports/sockets 13 for the attachment of stand-off insulators 14 (is shown stick insulator), used for maintenance current-carrying busbars.

Lever 15 is mechanical position indicator of switch. Switch and its drive are established/installed on reinforced concrete bed 16.

Fig. 17-25 are given two bits of the arc-suppression chamber/camera, shown during the cutoff/disconnection of switch.

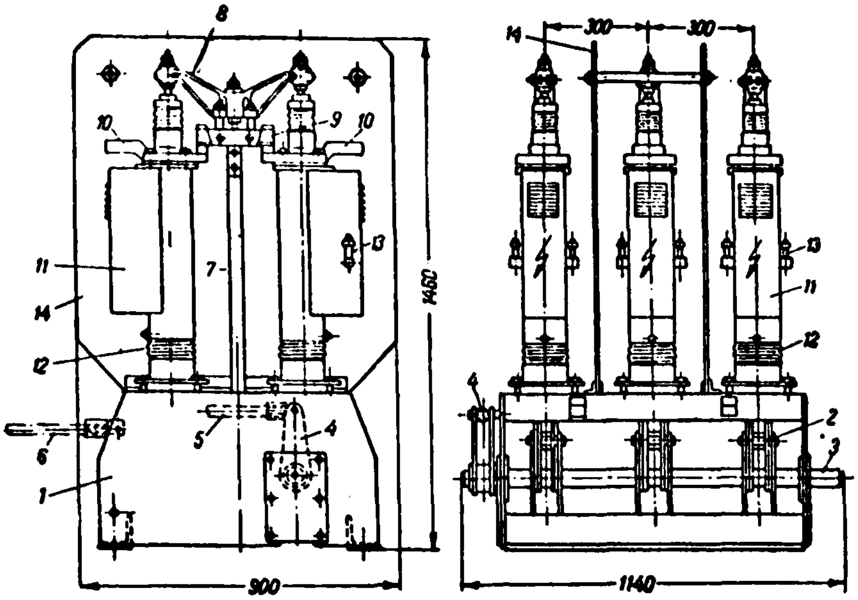

Fig. 17-23. An oil breaker of the type MGG-10 on 10 kV, 2000 A, 500 MVA. 1 - frame; 2 - drive mechanism; 3 - shaft; 4 - lever; 5 - thrust/rod to the drive; 6 - stay rod; 7 - insulating rod; 8 - contact crosshead, which carries the slide contacts; 9 - the make contacts; 10 - terminals/grippers for the connection of the busbars; 11 - tank, 12 - stand-off insulator; 13 - oil gauge; 14 - insulating partition.

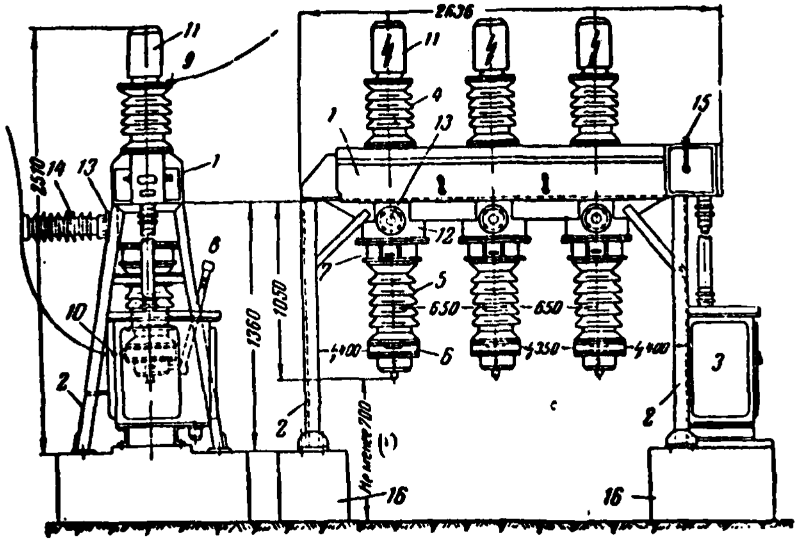

Fig. 17-24. Oil switch type MG-35 for 35 kV, 600 A, 500 MVA with the electro-magnetic drive type ShPS-20 for external unit.

Key: (1). It is not less.

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By insulating disk 1 chamber/camera is divided into two parts. Lower **2 are gas-generating part of the chamber/camera, and upper** 3 - **arc-suppression.**

Contact device consists of fixed contact 4, intermediate contact **5 and movable contact bar 6.**

Fixed contact 4 is established/installed on the clamp of 7 intermediate collars 8. To the latter is fastened/strengthened terminal/gripper by 9 for the connection of the current-carrying busbar.

The steel housing 2 of gas-generating parts of the chamber/camera, intermediate collar 8 and disk 1 are fastened/strengthened to the collar of porcelain cover 20.

Intermediate contact 5 is fastened/strengthened between two insulating cheeks 15, which can be turned on axis 18. Intermediate contact is equipped with spring 16 and lever system 17. The latter is connected with piston rod 19, which is located within cylindrical turning in disk 1.

The gas-generating part of the chamber/camera with the aid of openings/apertures 21 in disk 1 is communicated with the upper arc-suppression part of chamber/camera 3.

Upon the start of switch slide contact 6 enters kV chamber/camera 3 and, in passing by it, it rests into upper spherical form the cap of intermediate contact 5. The latter is turned clockwise, spring 16 is pressed. In end lower position the right flat/plane cap of contact 5 is pressed against fixed contact 4. Path

of current in the connected position of the switch: slide contact 6, intermediate contact 5, fixed contact 4, clamp 7, terminal/gripper 9.

With the cutoff/disconnection of switch slide contact 6 moves upward. Are first broken contacts 4 and 5, between which appears gas-generating arc 22. Pressure in chamber/camera 2 is raised. Intermediate contact under spring effect 16 follows the slide contact. If is disconnected relatively small current, then intermediate contact is turned until it is rested into disk 1, make tight its central opening/aperture 11. In this case gas-generating the friend reaches the maximum length. After this slide contact blows away from intermediate and between them appears quenched an arc 23. Under effect of pressure in the gas-generating part of the chamber/camera oil from it through openings/apertures 21 in disk 1 and slot 10 and 12 in the upper part of chamber/camera 3 falls into the field of the quenched an arc, near which occurs the violent generation of gas. The gases, which escape from slot 10, create longitudinal blast, and from slots 12 - a head-on blast (arrows/pointers 13).

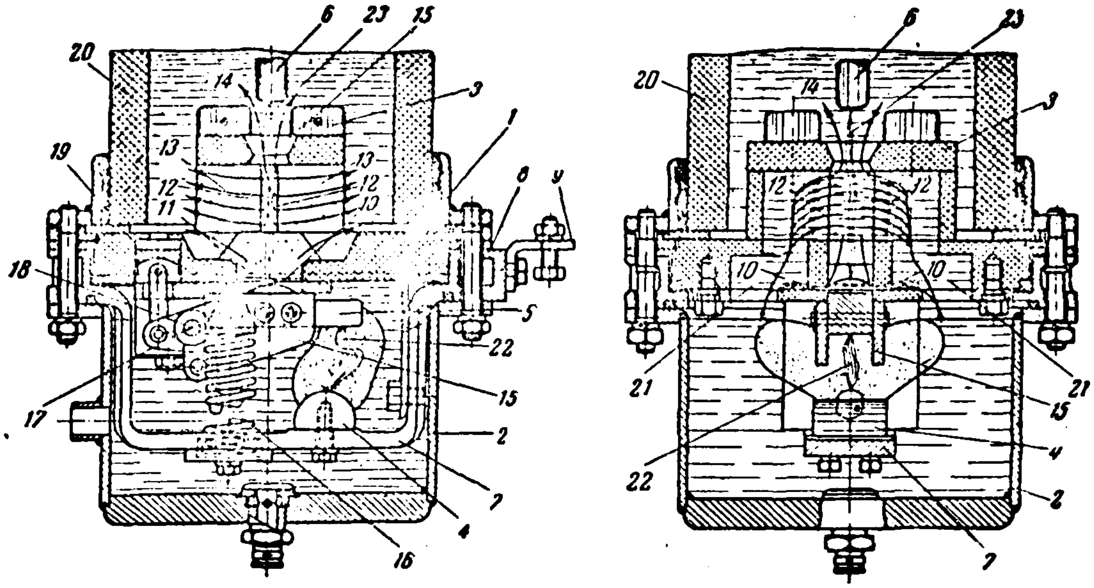

Fig. 17-25. Arc-suppression chamber/camera of an oil breaker of the type MG-35.

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With further extension of arc is opened/disclosed upper central opening/aperture 15, into which is fixed the longitudinal flow of gas 14, which ensures arc extinction with any small disconnected current.

In the case of the cutoff/disconnection of high current in the gas-generating part of the chamber/camera is created the large pressure under action of which piston 19 is displaced upward.

Respectively is displaced lever system of 17 intermediate contacts, as a result of which decreases the course of the intermediate contact: it is stopped earlier, rather than it will reach disk 1. By these is limited the length of the gas-generating arc and, consequently, also the value of pressure in the gas-generating part of the chamber/camera. In this case the quenched an arc, which was being formed between stopping in intermediate position contact 5 and rod 6, is extinguished under the action of the energetic longitudinal gas flow, which emerges through the gap between rod 6 and walls of central opening/aperture 11 in disk, i.e., earlier than contact 6 it will leave this central opening/aperture.

The tripping time of switch with the cutoff/disconnection of its rated current of cutoff/disconnection is approximately/exemplarily 0.08 s. Weight of oil in three phases of approximately 36 kg.

A switch of the type MG-35V for internal installation greatly little differs from that described: in terms of the location of the drive which in this case is established/installed not in the end/face of switch as on Fig. 17-24, but before the front of switch, the somewhat smaller length of frame and the fulfillment of some other parts [17-3].

Small volume oil breakers to voltage 110 kV. To the voltage

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indicated the plant "electrical device" manufactures a small volume switch of the type MG-110 in nominal power of cutoff/disconnection 2500 MVA, intended for external installation.

Switch has three identical phases which either mechanically connect up one assembly with common drive (Fig. 17-26), or they supply each phase with independent drive, i.e., realize phase-by-phase control.

On welded frame 1 is established/installed hollow porcelain stand-off insulator 2, on which is fastened/strengthened the housing of 3 mechanisms of the motion of contacts (23 in Fig. 17-27a). Toward the housing indicated are inclined attached two arc-suppression chambers/cameras 4, equipped with emergancy valves 5 and gas bleeders with oil separators 6. Terminals/grippers 7 and 8 serve for the connection of busbars.

Stand-off insulator 2, housing 3 and arc-suppression chambers/cameras 4 are oil-filled. For the checking of the level of 10 oils serves oil meter tube with 9.

Within frame 1, established/installed on bed 11, is located shafting of 12 phases on which are rigidly fastened/strengthened rocker shaft arms 13 and 15.

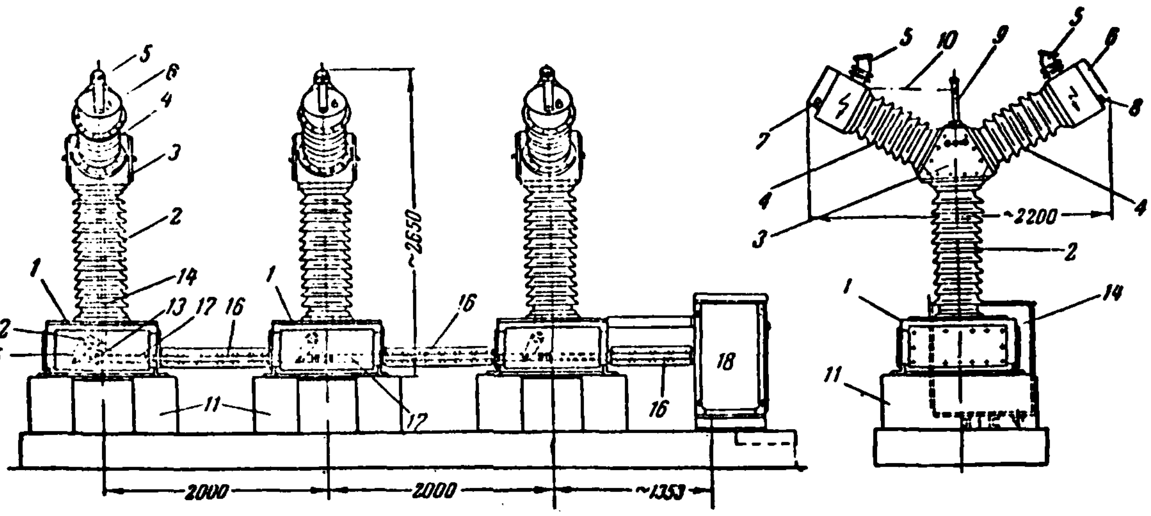

Fig. 17-26. An oil breaker of the type MG-110 on 110 kV, 600a, 2500 MVA with electromagnetic actuator of the type ShPS-30.

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Lever 13 is hinged connected with insulating rod 14, which passes within stand-off insulator 2 and in housing 3 with linkage it is connected with the slide contacts of arc-suppression chambers/cameras.

The levers of 15 three phases are connected with rods 16 between themselves and with drive 18. Within frames 1 on rods 16 are established/installed disconnecting springs 17.

The section/cut of one arc-suppression chamber/camera of the switch in question is given in Fig. 17-27a. The contacts of chamber/camera are shown in the off position of switch.

Chamber casing is made from thick-walled bakelite cylinder 19, placed inside porcelain cover 4, fastened/strengthened inclined to housing 3.

In each chamber/camera are three end-type of the contact: motionless 20, intermediate 21 and movable 22. First two are equipped with springs. Intermediate contact is established/installed in the opening/aperture of textolite disk 26, which divides cylinder 19 into two parts. It is direct above the gap of contacts 20 and 21 is fastened/strengthened textolite partition (barrier) by 28 with two slots 27.

Slide contact 22, passing through the central opening/aperture in figure collar 25 (nonmagnetic cast iron), with the aid of linkage 23 is connected with rod 14. The slide contacts of two chambers/cameras are connected by flexible current-carrying connection/communication 24.

From the combined examination of Fig. 17-26 and 17-27a it is possible to see that upon the start of the switch when drive 18 moves

rods 16, rocker shaft arms 15 and 13 are turned against the rotation of hour hand and rod 14 is moved upward. Motion by the latter through levers 23 is transmitted to the slide contacts of 22 both chambers/cameras. In passing by small distance, slide contact rests in intermediate contact 21 and moves it to contact with fixed contact 20 (diagram in Fig. 17-27b).

With the cutoff/disconnection of switch under the action of the disconnecting springs 17 rod 16 move in opposite direction and rod 14 is moved downward, driving the contacts of arc-suppressing chambers/cameras. First all three contacts of chamber/camera move together. First reaches the backstop and is stopped contact 20 and between it and intermediate contact 21 it appears the arc of small length (47 mm), which burns in immediate proximity of slots 27 in partition 28. Then reaches the backstop and is stopped intermediate contact and between it and slide contact it appears the second arc. As a result of evaporation and decomposition of oil by the arc, which burns between contacts 21 and 22, which is gas-generating, pressure in chamber/camera sharply increases, and oil through openings/apertures in disk 26 (in Fig. 17-27a they are not shown) begins intensely to be forced into the zone of the quenched an arc, which burns between contacts 20 and 21.

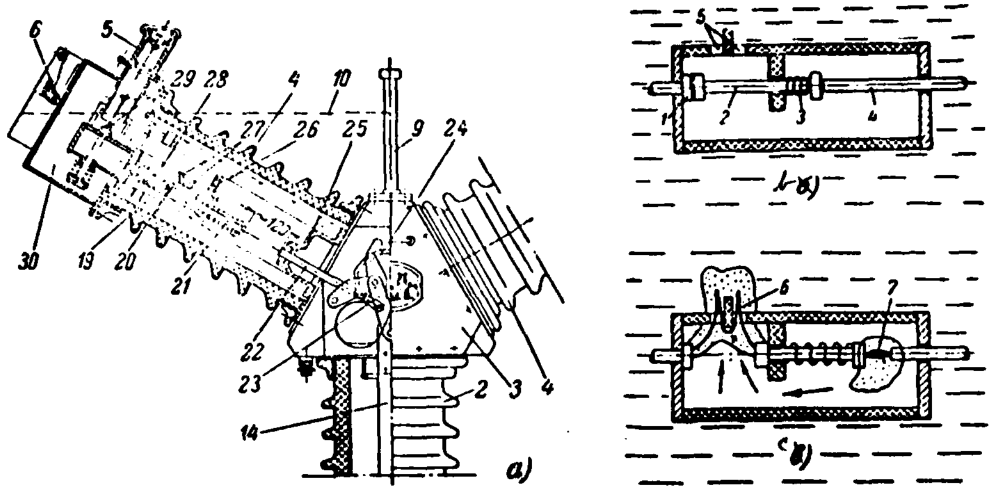

Fig. 17-27. The arc-suppression chamber/camera of an oil breaker of the type MG-110 (is continued the numbering of the parts of Fig. 17-26). a) the off position; b) the diagram of chamber/camera cutoff/disconnection.

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Because of the presence of slots 27 appears the transverse blast (diagram in Fig. 17-27c), which energetically deionizes the quenched an arc and its ensuring extinction.

Thus, in the chamber/camera in question first is formed the quenched an arc, and only after the achievement by it of the specific

length, which corresponds to width of both slots 27, is formed gas-generating arc. The length of the latter is not constant and depends on the strength of disconnected current: the greater the disconnected current, by the fact at the smaller length of the gas-generating arc is provided the necessary pressure for the extinction of the quenched an arc. With the cutoff/disconnection of the rated current of the cutoff/disconnection of switch the time of arc extinction is 0.02-0.03 s, and the full/total/complete tripping time of approximately/exemplarily 0.08 s.

Within located under voltage jacket 30 is placed spring safety valve 29, which limits pressure in arc-suppression chamber/camera with the cutoffs/disconnections of the high currents (are opened/disclosed at a pressure more than 10 atm(tech)).

Oil breakers of the type MG-110 are sufficiently simple structurally/constructurally and are reliable. As deficiencies/lacks it is possible to note the comparatively small disconnecting ability and the use of large-size large-diameter porcelain, which will raise in price switch and increases its weight: the weight of oil in three phases is 600 kg with the total weight of switch with drive 4.3 t. Are true, these weight characteristics considerably better than the analogous characteristics of multi-volumetric oil breaker to the same voltage of the type MKP-110 (weight of oil 8.5 t and total weight

18.3 t), but it is nevertheless still great.

Brief information about the foreign constructions/designs of small volume oil breakers. Abroad construct small volume switches to all in practice used voltages and at power the cutoffs/disconnections to 12,000 MVA.

At voltages to 35 kV small volume switches construct both with the steel tanks and with tanks from insulation. All these switches have many similar features with the small volume oil breakers of Soviet plants.

In small volume oil breakers to large voltages are used extensively the porcelain elements/cells of small diameters, which not only considerably facilitates and reduces the cost of switches, but it makes it possible to reach the large power of cutoff/disconnection.

In recent years, some European firms are manufacturing low-capacity oil switches of the suspension type for external 40-60 kV units. They are suspended on the garlands of insulators for metal or ferroconcrete portals of distributing units.

Fig. 17-28 in the form of an example schematically shows suspension oil breaker to 220 kV and power of cutoff/disconnection 5000 MVA (firm Dell, France). Each phase, carried out in porcelain housing 1, is suspended/hung to support 2 from four garlands of

suspension insulators 3.

Suspension switches have, as a rule, phase-by-phase control, realized by a mechanism, which composes one whole with the phase of switch and which are located under voltage. Effect on this drive mechanism of phase is realized remotely with the aid of pneumatic (by compressed air) or oil-pneumatic (by pressure oil control. In both cases the cabinet of control of 4, adjusted at the level, convenient for maintenance/servicing, is connected with the phase of switch by tubes from insulation, prisoners inside porcelain tube 5.

Thus, suspension switches do not have complicated drives, common for other types of oil breakers, and also there are no complicated drive mechanisms, which connect the phases between themselves and with the drive; are maximally simplified the drive mechanisms of independent phases. All this considerably simplifies the construction/design of switches, increases the reliability of their operation, it decreases their cost/value and simplifies operation.

Since the phases of such switches are suspended on string insulators, then already there is no need for applying expensive porcelain covers for the arc-arresting devices/equipment, and it proves to be possible to perform these covers from another, cheaper and more reliable insulation [17-1 and 17-4].

Overall sizes and weight of suspension small volume oil breakers are considerably less, rather than multi-volumetric oil breakers to the same parameters. For example, if the weight of three phases of suspension switch on 220 kV of the construction/design, similar to that shown in Fig. 17-28, is approximately/exemplarily 7-7.5 t, then weight multi-volume oil breaker to the same voltage even with the most rational form of tank (for example, according to the type, given in Fig. 17-11) is approximately/exemplarily 30-36 t, i.e., 4-5 times larger. Is reached a considerable savings of metal and insulation.

17.4. Auto-gas switches.

The arc-suppression devices/equipment of auto-gas switches supply with launcher adapters of the electrical insulating material, which generates gases under the action of the high temperature of arc. These gases are utilized for an arc extinction.

As gas-generating material can be used the fiber, organic glass, etc.

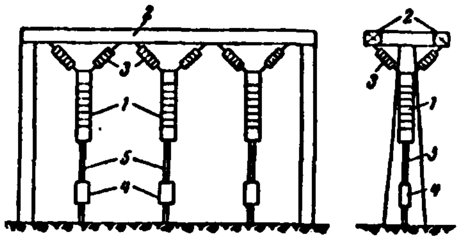

Fig. 17-28. Diagram of installation of suspension small volume oil breaker on 220 kV, 5000 MVA.

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Organic glass was widely applied as a result of the large gas-generating ability and a small wearability under the action of electric arc.

Forming gases can be used for organizing the longitudinal or transverse blast. Larger effect gives the transverse blast when it is possible to create the more intimate contact of arc with the surface of the gas-generating material, as a result of which is provided more intense generation of gas and blast. Is utilized also the effect of narrow slot.

Fig. 17-29 shows general view, while in Fig. 17-30 - arc-suppression chamber/camera of an auto-gas switch of the type

VG-10 (switch gas-generating) of plant "electrical device" to nominal voltage 10 kV and power of cutoff/disconnection 300 MVA.

The housing of arc-suppression chamber/camera is made from two getinax plates 1 and placed between them textolite insert 2. Inside which there are longitudinal and transverse channels. In longitudinal channel are located made from organic glass launcher adapters 4 and shutter/valve 5; the latter are equipped with springs 6. Chamber/camera is tightened by pins 7.

On contact bar 8 are attached motionless point contacts by 9 with guard ring 10 (according to the type of the contacts, given in Fig. 12-14).

Upon start flat/plane slide contact (8 in Fig. 17-29) enters between plates 3, it separates/expands shutters/valves 5 and then it enters into fixed contacts 9. In the connected position transverse channel 14, which communicates buffer space 13 with gas bleeder 11, is overlapped by the body of slide contact.

In the process of cutoff/disconnection the arc first is formed between fixed contacts and contact knife, but after the output of the latter from guard ring 10 arcs burn between this ring and slide contact. Under the action of the high temperature of arc is

separated/liberated a large quantity of gases and pressure in the upper part of the chamber/camera is raised. Valve 12 is opened/disclosed, and space 13 is filled with gases under pressure. As soon as knife will discover transverse channel 14, appears intense transverse blast.

Bases from space 13 rush through a narrow rectangular channel to a gas outlet, carrying the arc along behind them. A close contact of the arc with the walls of the narrow channel is created which intensifies the evolution of gas and the de-ionization of the arc. The arc is finally extinguished with the first or second passing of the current through zero after the start of blast.

In the case of the cutoff/disconnection of low currents when pressure in space 13 is small, the speed of blast is small and arc extinction is involved/tightened. During further motion of slide contact the arc is lengthened also on its output from shutters/valves 5 latter converge and fasten arc. Arc proves to be burning in the narrow slot between shutters/valves from the gas-generating material, which provides its deionization and extinction.

The tripping time of switch with the cutoff/disconnection of the rated current of cutoff/disconnection is approximately/exemplarily 0.14 s.

The expenditure of the gas-generating material for each cutoff/disconnection is small. The most abraded parts are carried out interchangeable.

Gas bleeder 11 is filled with the short cuts of the copper tubes passing between which gases they are cooled and they are deionized.

Advantages of the switch: explosion- and fire safety, absence of the liquid arc-arresting medium, operational simplicity. Deficiencies/lacks: considerably greater weight and cost/value in comparison with small volume oil breakers of the type VMG-133, which have moreover, and the best parameters.

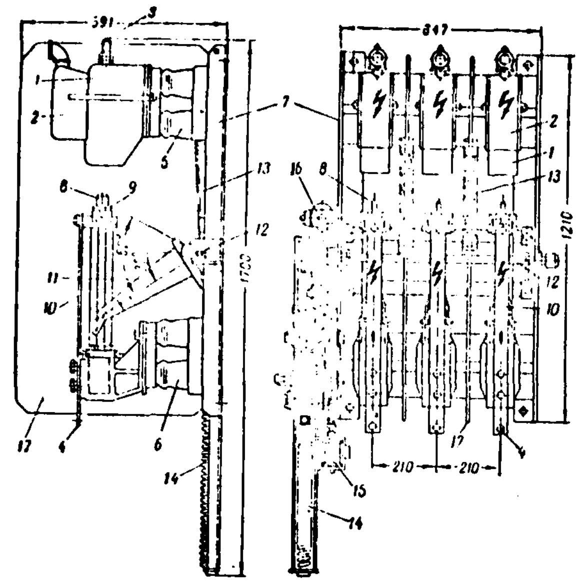

Fig. 17-29. Auto-gas switch of the type VG-10 on 10 kV, 400A, 300 MVA. 1 - arc-suppression chamber/camera; 2 - gas bleeder; 3 and 4 - terminals/grippers for the connection of the busbars; 5 and 6 - the stand-off insulators; 7 - frame; 8 - flat/plane slide contact; 9 - slipping contacts; 10 - current-carrying bus; 11 - getinax lever; 12 - shaft; 13 - disconnecting springs; 14 - including spring; 15 - clutch magnet; 16 - disconnecting electromagnet; 17 - isolating partitions.

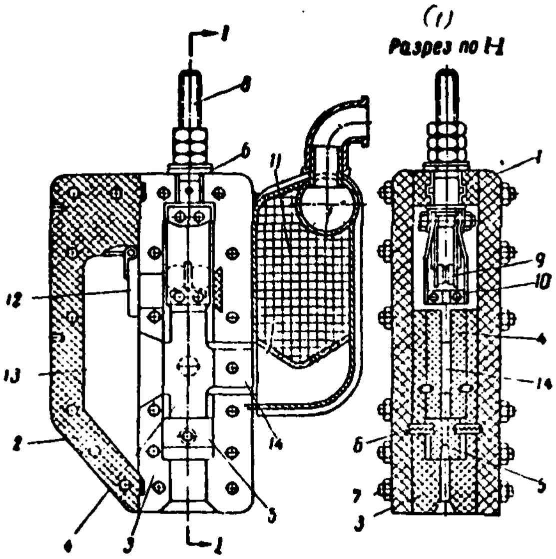

Fig. 17-30. Arc-suppression chamber/camera of an auto-gas switch of the type VG-10.

Key: (1). cross-section.

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A switch of the type VG-10 has switching on spring 14, which they start with the aid of manual rigging. In order to bring spring, it is necessary by the handle of drive to complete four motions (downward - upward - downward - upward). The brought spring is held by trip and proves to be that engaged through the mechanism of the free release (see §15-2) with rocker shaft arm on the shaft of switch. For the start of switch it is necessary to free the trip indicated, which holds the switching on spring in the stretched state. This is done by hand with the aid of the special lever (in Fig. 17-29 it is not shown) or is remote with the aid of clutch magnet 15, the feed circuit of which close with the aid of the appropriate knob/button or key/wrench controls.

If we with the connected switch bring the switching on spring, then after cutoff/disconnection under the action of relaying it can be connected conversely (single automatic reset).

If necessary the switch can be equipped with electromagnetic

actuator of direct current.

Switches of the type VG-10 are suitable only for internal installation.

To the voltages of above 10 kV auto-gas switches do not manufacture as a result of difficulties in the achievement of the necessary insulation.

17-5. Air circuit breakers.

General information. In air circuit breakers the arc is extinguished with the aid of blast by the compressed air, which enters from the reservoir, established/installed near switch or, which is more frequently, that constitutes one whole with its foundation (frame, trolley). Into the reservoirs of switches the compressed air comes from blowing plant.

Air circuit breakers work at different air pressure, it is more frequent at a pressure 8-20 atm(gage). So, Soviet switches are calculated for nominal air pressure in reservoirs 20 atm(gage).

The arc-suppression devices/equipment of air circuit breakers are performed with one and several disruptions in phase and with

longitudinal or transverse air blast.

Let us become acquainted with the principle of equipment and work of air circuit breakers based on the example of the simplest switch with one disruption to phase and longitudinal blast whose diagram is given in Fig. 17-31; there is shown the schematic diagram of control of switch.

Upper part 1 is arc-suppression chamber/camera, and lower 2 - by the air drive, which uses for start and cutoff/disconnection of switch. Busbars terminate 11 and 12. Path of current in the connected position: terminal/gripper 11 - the cover/cap of 5 chambers/cameras - motionless tubular contact 4 - movable circular contact 3 - slipping contacts 9 - ferrule 8 - terminal/gripper 12.

The compressed air can enter switch from the reservoir through disconnecting OK or switching on VK relief valves which can be opened by hand or remotely with the aid of with respect disconnecting OE or switching on VE of the electromagnets whose circuits are closed by the knob/button of cutoff/disconnection O or by the knob/button of start V. During functioning of the relay of protection RZ the switch is disconnected automatically.

With cutoff/disconnection the compressed air from the reservoir

through the valve OK enters arc-suppression chamber/camera 1 and into the upper part of the cylinder of 2 drives. Under the action of the compressed air piston 10 is moved downward. Together with piston is moved downward slide contact 3; between contacts 3 and 4 is formed the arc. Since up to this moment/torque chamber/camera 1 proves to be that filled with the compressed air, then simultaneously with striking of the arc the compressed air is fixed into the opening/aperture of contact 4 and blows out the encountered on its path arc as this shown in the diagram a Fig. 17-31. From the internal cavity of contact 4 air falls into the cap/hood of 6 explosion chambers and through openings/apertures 7 emerges outside. Is especially energetically arc gap is deionized at the moment of transiting the current through zero. Usually the process of extinguishing of arc concludes upon first or second transfer of the current through zero.

The circuits of the electromagnets of control OE and VE are brought through blocking contacts of the type KSA, connected with the movable system of switch.

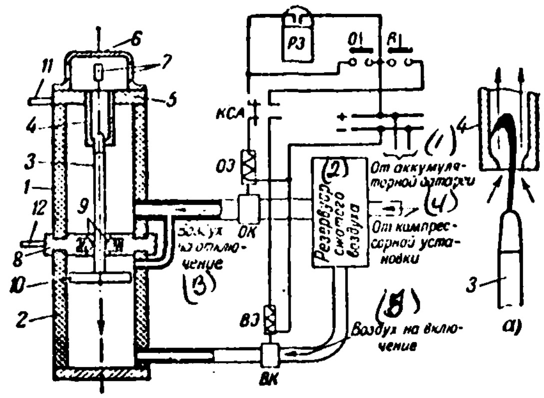

Fig. 17-31. Schematic of the device/equipment of air circuit breaker without separator and schematic diagram of control of it.

Key: (1). From storage battery. (2). reservoir of compressed air. (3). Air OK to cutoff/disconnection. (4). From blowing plant. (5). Air for start.

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During completion of process/operation the contacts KSA automatically are changed over, the circuit of the electromagnet of the corresponding valve is disrupted and valve is closed - air supply ceases.

In the end lower position of slide contact is provided the

necessary air gap between contacts 3 and 4, i.e., the insulation of disruption at atmospheric air pressure in chamber/camera.

In the examined simplest switch with longitudinal air blast the contacts in the process of cutoff/disconnection always diverge and arc length increases, until it finally goes out. It is logical that in this switch for decreasing the tripping time the rate of the motion of contacts must be possibly greater.

The studies of air circuit breakers showed [17-5 and 17-6] that the best conditions for the extinction of electric arc in the longitudinal flow of the compressed air are reached at certain specific distance between contacts, which depends on the value of voltage, the disconnected current, the air pressure and series/row of other factors. Therefore, if the contacts of switch at a high speed dilute up to the considerable distance, necessary for achievement of the proper value of the insulation of disruption, then at the moment of transition/junction through zero arcs currents the distance between contacts proves to be, as a rule, not equal to optimum for the conditions for arc extinction, that, naturally, it manifests itself the value of the disconnecting ability of switch.

Therefore most rational is rapid separation of the contacts of switch only up to such distance, with which are provided the best

conditions for arc extinction. But this distance is usually so small that it cannot ensure the necessary insulation of disruption at atmospheric air pressure, i.e., after the cessation of the supply of the compressed air into explosion chamber.

In air circuit breakers with longitudinal blast the best conditions for arc extinction with the subsequent guarantee of the proper insulation of disruption after the termination of arc extinction are achieved by one of the following methods:

1. With the cutoff/disconnection when chamber/camera is filled with the compressed air, contacts rapidly dilute by the distance, most favorable for an arc extinction, and are delayed in this position to a period, a somewhat exceeding period of arc extinction. Then contacts dilute up to the distance, which ensures necessary dielectric strength of gap/interval at atmospheric pressure. In this position the supply of the compressed air into chamber/camera ceases.

2. Besides contacts in arc-suppression chamber/camera each phase of switch is supplied with supplementary contacts, with so-called separators, which have their drive. In this case after the supply of the compressed air into explosion chamber the contacts of the latter rapidly dilute up to the distance, determined by the conditions for arc extinction, and then through the small time interval, which a

little exceeds the time of arc extinction, it comes into action the air drive of separator and the latter is disconnected, creating final chain cleavage. In these switches after the cutoff/disconnection of separator the air intake into explosion chamber ceases, the contacts of switch under spring effect again are closed and circuit proves to be that brought only by separator. The start of this switch is realized by start of separator.

3. The same as in first method, but with that difference, that after arc extinction chamber/camera remains that filled with compressed air, which requires smaller supplementary thinning of contacts. After thinning of contacts up to supplementary distance automatically are closed exhausts of chamber/camera and it remains under pressure. In this case necessary dielectric strength of gap/interval is provided with the smaller course of contacts, that somewhat simplifies the construction/design of switch.

With respect to the aforesaid air circuit breakers with longitudinal blast divide into switches without separators, with separators and those air-filled. The special features/peculiarities of the device/equipment of these switches are examined below.

Fundamental advantages of air circuit breakers: the absence of liquid medium and harmful gas-generating materials, explosion- and

fire safety, short tripping time, reliability of operation, possibility of frequent starts and cutoffs/disconnections, absence of the powerful/thick drives of direct current, smaller weight in comparison with multi-volumetric oil breakers. Air circuit breakers can be constructed to any voltages and to the very large power of cutoff/disconnection.

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To deficiencies/lacks in air circuit breakers can be attributed: the relative complexity of construction/design, high cost/value and a somewhat larger complexity of operation in comparison with oil breakers, and also a need for air economy, into which enter compressor motors, reservoirs, air ducts and other equipment.

Air circuit breakers with the chambers/cameras of longitudinal blast without separators usually make for voltages not above 35 kV, since with large voltages the mass of the moving elements of the switch is obtained such large that for their rapid movement and subsequent stop are necessary the very powerful/thick pneumatic drives and oil dashpots.

As an example of air circuit breaker without separator let us examine Soviet switch to voltage 35 kV of the type VVN-35 (Fig. 17-32

and 17-33). The trolley of 1 switch is carried out as one whole with its delivery air chamber 2, in bottoms of which are provided hatches 3. Trolley is equipped with rotary rollers 4.

On trolley are established/installed the columns of three phases, consisting of the lower collar of 5, two hollow supporting porcelain insulators 6 and 7, average/mean collar 8 cap 9. Insulator 7 is the housing of arc-suppression chamber/camera.

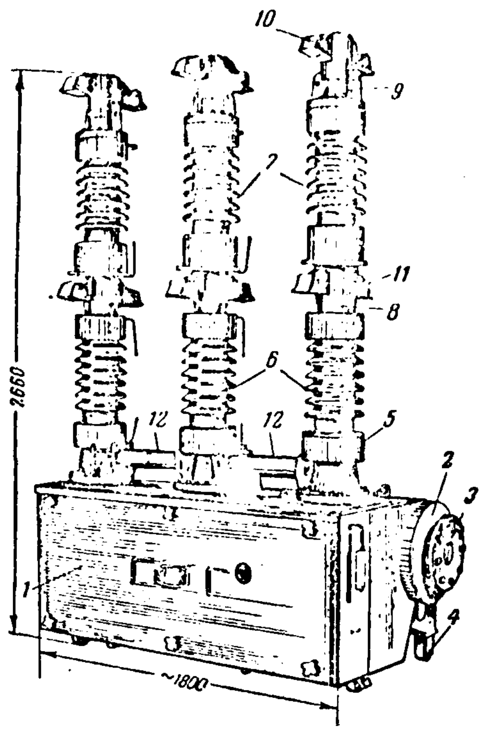

Fig. 17-32. Air circuit breaker of the type VVN-35 on 35 kV, 1000 a, 1000 MVA.

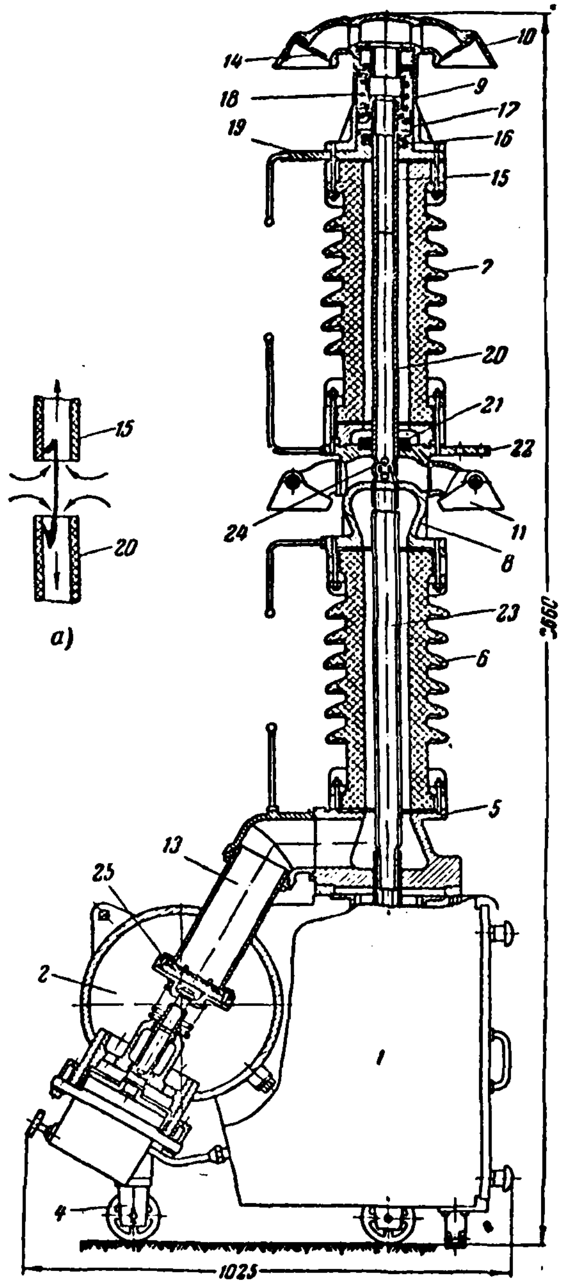
10
14
9
18
17
19
16
15
7
20
21
22
24
11
8
23
6
5
13
25
2
1
4
1025
2560
15
20
a)

Fig. 17-33. Section/cut on average/mean phase of air circuit breaker of type VVN-35 (is continued numbering of parts of Fig. 17-32).

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Each pole of switch has two hollow tubular contacts (one disruption to phase): upper 15 and lower 20. In cap 9 is placed the mechanism of the movement of front contact, which consists of piston 17, into which is screwed tubular contact 15, and springs 18, which wrings out it downward and ensuring the necessary pressure of contacts 15 and 20. Through sliding contacts 16 front contact 15 is electrically connected with terminal/gripper 19, which uses for the connection of busbars.

Lower movable tubular contact 20 is attached on insulating rod 23 and through slipping contacts 21 is connected with average/mean collar 8 and terminal/gripper 22 for busbars. In the lower part of contact 20 are openings/apertures 24, which in the connected position of switch are located against exhausts 11 in average/mean collar.

Path of current with the connected switch: terminal/gripper 19 - contacts 16 - front contact 15 - back contact 20 - contacts 21 - terminal/gripper 22.

The rods of 23 three phases of switch are hinged connected with the levers of the drive mechanism, arranged/located within frame 1. There is located the pneumatic drive, with the aid of which the rods with slide contacts 20 are moved with start and cutoff/disconnection of switch.

With cutoff/disconnection is opened/disclosed valve 25 and the compressed air from reservoir 2 along tubes 12 and 13 (Fig. 17-32 and 17-33) enters the internal cavity of insulators 6, and of them through channels in the average/mean collars (in Fig. 17-33 they are not shown) into the explosion chambers of 7 three phases. From the explosion chambers through openings/apertures in the collar of cap 9 (in Fig. 17-33 they are not shown) the compressed air enters space under piston 17 and is risen the latter together with contact upward approximately/exemplarily on 30 mm; spring 18 is presssed. Between contacts 15 and 20 appears the arc, which immediately undergoes intense blowing, as shown in diagram in Fig. 17-33a. Arc is blown away to the internal surface of hollow contacts 15 and 20, which protects of decomposition the working end-type parts of the contacts. Air passes inside contact 15, it falls into cap 9 and emerges in the atmosphere through exhausts 10. The air, which enters inside contact 20, emerges in the atmosphere through its lower openings/apertures 24 and exhausts 11.

The time of arc extinction usually is not more than two-three half-periods.

The pneumatic drive of switch is controlled so that it operates/wears immediately after arc extinction. Drive turns the shaft of switch and with the aid of rocker shaft arms rapidly abstracts/removes downward rods to 23 with contacts 20, than and it is created the insulation of disruption. After this air intake into chamber/camera 7 automatically it ceases, and contact 15 under spring effect 18 is omitted to initial position.

The tripping time of switch (to arc extinction between contacts 15 and 20) does not exceed 0.1 s. However, the full/total/complete time of action of switch taking into account the time of the motion of contact 20 is approximately/exemplarily 0.3 s.

Is connected switch by the same pneumatic drive, which has bilateral action, which moves upward to contact 20 to their contact with contacts 15. In this case the air into explosion chamber does not enter.

Exhausts 10 and 11 are equipped with deflectors and are closed with shutters/valves 14 with the springs, which block penetration into the chamber/camera of dust and snow. With cutoff/disconnection

the compressed air opens/discloses shutters/valves and it emerges outside.

Air circuit breakers with the chambers/cameras of longitudinal blast and separators can be prepared to any voltage; however, most frequently the separators apply in switches by voltage 110 kV even above. Separators can be located outside switch (external separators), also, within switch (internal separators). External separators create the visible chain cleavage.

The schematic diagram of air circuit breaker with external separator is given in Fig. 17-34, where the similar/analogous parts are designated by the same numbers, as in Fig. 17-31. The schematic diagram of control is not shown, since it is similar to that given in Fig. 17-31.

The separator of switch consists of moving contact knife 13, fixed contacts 14, fastened/strengthened to stand-off insulator 15, and pneumatic drive 16 with two-way piston 17. The latter has a guide, entering the plugs, attached on the axis of 18 separators. With the displacement/movement of piston this guide revolves axis 18 and it switches on or disconnects knife 13.

Contacts movable 3 and motionless 4 are performed tubular. Slide

contact is equipped with spring 20; with cutoff/disconnection it moves downward in guiding tube 21.

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In the connected position of switch the current passes through the following parts: 11-5-4-3-9-8-13-14-12 (ring 8 and knife 13 are connected by flexible member which in the diagram is not shown).

With the cutoff/disconnection of switch is opened/disclosed the valve OK and compressed air fills explosion chamber 1 and it enters space above piston 10. The latter together with contact 3 is moved downward, contacts 3 and 4 are broken also between them ignites the arc. Since up to this moment/torque chamber/camera 1 is filled with the compressed air, then simultaneously with striking of the arc appears energetic longitudinal blast and arc is involved/tightened inside tubular contacts (outline a in Fig. 17-34), its length increases. All this leads to extinction into one-two half-periods. Air is passed inside the tubular contacts and it is blown out outside through exhausts 7 and 22. During cutoff/disconnection spring 20 is pressed and remains in this position until is opened valve OK.

Simultaneously with filling of chamber/camera air along channel 19 enters the right side of the cylinder of the pneumatic drive of 16

separators. Under the action of the compressed air the piston is moved it to the left and disconnects knife (position 13'). The action of the pneumatic drive is controlled so that knife 13 is disconnected only after arc extinction between contacts 3 and 4, when in current circuit there is no.

In the off position of knife are changed over blocking contacts (KSA in Fig. 17-31) and valve OK it is closed. Simultaneously under spring effect 20 contacts 3 and 4 are closed, but circuit remains off the knife of separator.

In order to include/connect switch is opened/disclosed the valve VK, through which the compressed air enters the left side of the cylinder of the drive of separator. Piston 17 is moved it to the right and switches on the knife of separator. Thus, switch is included by the knife of separator, that it is not dangerous even upon the inclusion to the existing in network/grid short circuit as a result of the large rate of the start of the knife of separator. In the case of start to short circuit operates/wears relaying, which closes the circuit of the electromagnet of the valve of cutoff/disconnection OK. The latter is opened/disclosed and switch is disconnected, as it is described above.

Air circuit breakers with one disruption to phase, as it takes

place in the examined simplest switch, manufacture usually by voltages not higher than 35 kV. Switches to large voltages have several disruptions to phase. A simplest and reliable constructive solution is use/application to the phase of several series-connected chambers/cameras of single disruption. This, in particular, it makes it possible to compose from a different number of one and the same chambers/cameras the arc-suppression devices/equipment of switches to different voltages.

Soviet plants produce in series of air circuit breakers with external separators of the type VVN to voltages 110-400 kV and nominal power of cutoff/disconnection to 15000 MVA (table P-14). They all are intended for external installation.

Fig. 17-35 shows the phase of a switch of the type VVN-110 to rated current 800A, voltage 110 kV and power of cutoff/disconnection 4000 MVA.

The arc-suppression device/equipment of switch has two gaps and is made from two series-connected identical chambers/cameras, which are located in porcelain jackets 1 and 1'. Is established/installed arc-suppression device/equipment on hollow porcelain insulator 2, which insulates it from trolley 3. Trolley is performed together whole with two delivery air chambers, connect/joined together and with blowing plant.

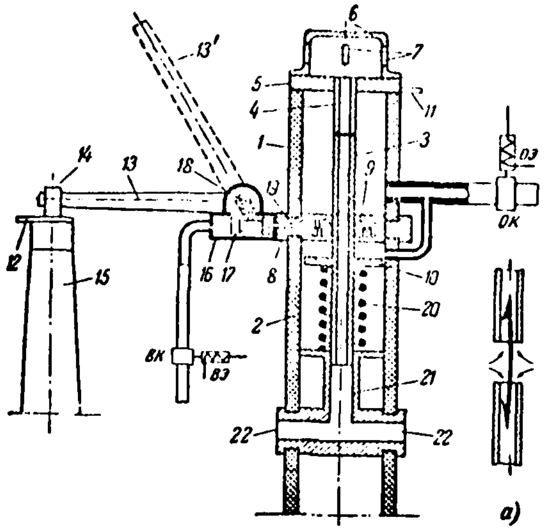

Fig. 17-34. Schematic of the device/equipment of air circuit breaker with external separator.

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In the forward section of the trolley is established/installed the cabinet of control of 10, in which is placed the electrical and pneumatic control of the phase of switch.

Separator is performed in the form of knife 4, equipped with air drive 5, established/installed in the middle part of the column. The fixed contacts of 7 separators are established/installed on the

column of pin insulators 6, mounted on the trolley of switch.

Each phase of switch is independent apparatus - there is no mechanical connection/communication between phases. Phases are connected only with the general/common/total system of electrical control - with start and cutoff/disconnection simultaneously are closed the circuits of the electromagnets of the valves of three phases.

The execution of switch in the form of three separate apparatuses considerably facilitates its transport and repair.

Fig. 17-36 gives the simplified circuit of the arc-suppression device/equipment of a switch of the type VVN-110. The arc-suppression devices/equipment of gaps are performed uniformly. In essence they consist of porcelain housing 1, brass housing 11, movable tubular contact 13 with piston 14, contact spring 15, which is guided tubes with 16 (within which moves contact 13 with cutoff/disconnection), slipping socket contact 19 and motionless tubular contact 20.

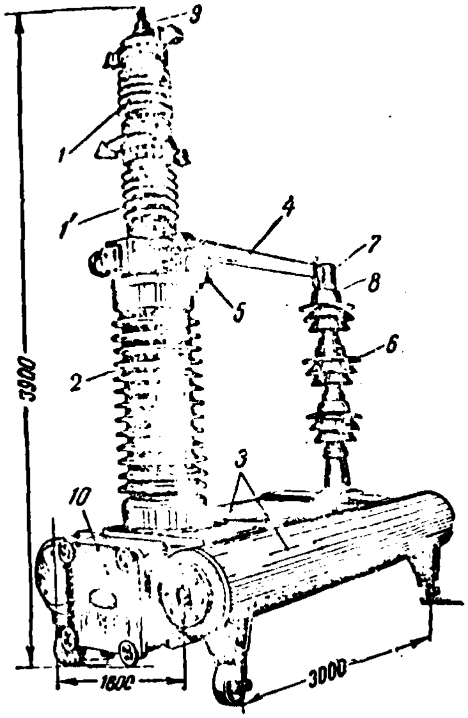

Fig. 17-35. Air circuit breaker of the type VVN-110 on 110 kV, 800a, 4000 MVA (one phase).

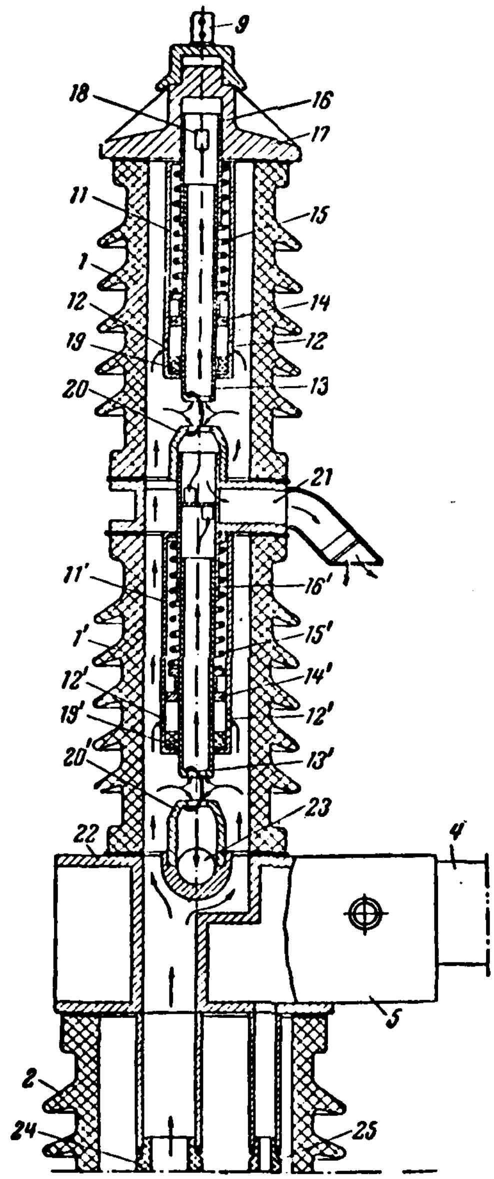

Fig. 17-36. Simplified circuit of arc-suppression device/equipment of

air circuit breaker of type VVN-110 on 110 kV.

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In the connected position of switch the current flows/occurs/lasts from terminal/gripper 8 through the knife of separator 4, collar 22, fixed contact 20', slide contact 13', socket contact 19', housing 11', fixed contact 20, slide contact 13, socket contact 19, housing 11 and cap/hood 17 to terminal/gripper 9.

With cutoff/disconnection is opened/disclosed the valve, which is located in the cabinet of control of 10, and air from reservoirs 3 along tube 24 stumbles inside insulators 1 and 1' and then through openings/apertures 12 and 12' inside housings 11 and 11'. Under the action of the compressed air on pistons 14 and 14' slide contacts 13 and 13' are moved upward and between contacts 13 and 20, and also 13' and 20' are formed arcs. Simultaneously through the internal cavities of tubular contacts and exhausts 18, 21 and 23 appears energetic longitudinal blast, as shown by rifleman/pointers. The time of arc extinction does not usually exceed two half-periods.

Since after the cessation of air supply into spark extinguisher the contacts of switch converge under spring effect 15 and 15', then switch is equipped with separator with air drive 5. Separator must be

disconnected automatically, but only after arc extinction on the gaps of switch. This is reached via the slower filling with the compressed air of the drive of separator. The knife of separator leaves the fixed contacts approximately/exemplarily after 0.05 s after interrupting of contacts in arc-suppression chamber/camera.

After the cutoff/disconnection of separator the control valve is closed and air supply in spark extinguisher ceases. Contacts 13-20 and 13'-20' are closed. Is connected switch by the start of separator by air drive 5 (air enters along tube 25). Taking into account the possibility of the inclusion to the existing in network/grid short circuit, the rate of the motion of the knife of separator at the moment of closing/shorting its contacts must be sufficiently great (8-12 m/s).

Soviet switches by voltages 154 kV and higher are arranged analogously, but they have a larger number of series-connected chambers/cameras: switches 154 kV - three chambers/cameras; 220 kV - four; 400 kV - six. Furthermore, all these switches have backs-out resistor, connected in parallel to the chambers/cameras of arc-suppression device/equipment, which provides the even distribution of voltage according to various gaps. The installation of such backs-out resistor is visible in Fig. 17-37, where is shown the phase of switch to voltage 220 kV.

If there are backs-out resistor, then with the cutoff/disconnection of switch separator disrupts the current, flowing through these resistors/resistances after arc extinction in arc-suppression chamber/camera. However, this current is small and its cutoff/disconnection is not dangerous for the knives of separator.

In the open installations, subjected to ice-covered surface, external separators can be covered/coated with the layer of ice, which strongly inhibits their work. For the successful decomposition of the layer of ice on the contacts of separator is necessary a corresponding increase in the power of its pneumatic drive and mechanical strength of its knife. All this complicates the construction/design of switch.

The deficiencies/lacks indicated are removed in switches with internal separators. However, internal separator in the housing, filled with air at atmospheric pressure, is bulky, especially with very high voltages. Is explained this by the significant magnitude of insulating gap/interval at atmospheric air pressure.

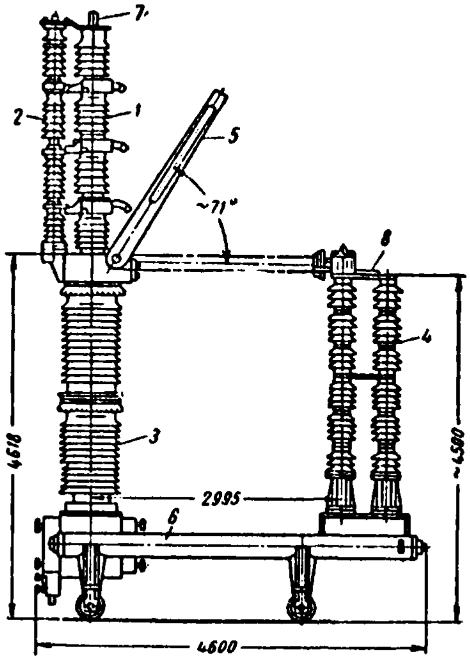

Fig. 17-37. Air circuit breaker of the type VVN-220 on 220 kV, 1000a 5000 MVA (one phase). 1 - arc-suppression device/equipment; 2 - backs-out resistor; 3 - the stand-off insulator; 4 - column of pin insulators; 5 - knife of the separator; 6 - delivery air chambers; 7 and 8 - terminals/grippers for the connection of busbars.

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It is essential to decrease the gap/interval indicated and, consequently, also the overall sizes of separator it is possible, after placing separator into the housing, filled with off separator

with the compressed air.

As an example Fig. 17-38 shows Soviet air circuit breaker to voltage 110 kV with air-filled separator 3. Arc-suppression device/equipment is performed just as in Fig. 17-36.

In the housing of 3 separators are motionless and slide contacts. Movable tubular contact is performed for one whole with piston and is equipped with spring. When switch is connected, then the internal cavity of the housing of separator is communicated with surrounding air i.e., in housing 3 pressure is equal atmospheric, and the contacts of separator under the action of its spring are locked.

With the cutoff/disconnection of switch the compressed air enters both into explosion chambers 1 and into the housing of separator 3. under the action of the compressed air the slide contact of separator is wrung out upward and it remains in this position, until housing 3 is found under pressure. The work of separator is controlled so that its contacts diverge only after arc extinction in spark extinguisher.

After the disagreement of the contacts of separator the blast valve of switch is closed and air supply in spark extinguisher 1 ceases and its contacts are closed. the housing of separator remains

under pressure always when switch is disconnected. For the start of switch it suffices to shut access of the compressed air into housing 3 and to report its internal cavity with surrounding air. Then under the action of the compressed spring the slide contact of separator is omitted and switch is included.

Certain deficiency/lack in the switches with the air-filled separators is the need for the careful multiplexing of the housing of separator, since it can long be found under pressure.

In contrast to the switches, shown to Fig. 17-35 and 17-37, switch in Fig. 17-38 have one delivery air chamber 5 and two cabinets of control of 6 and 7. The foundation of switch is performed without rollers. At present all Soviet air circuit breakers to voltages 110-400 kV are supplied with one delivery air chamber to phase and do not have rollers.

Tripping time of switch type VVN comprises not more 0.06-0.08 s (to arc extinction), and full/total/complete time of action taking into account tripping time of separator - approximate/exemplary 0.25-0.35 s.

The air-filled switches can be performed to any voltage, but most frequently them they perform by voltages 35 kV even higher.

Sufficient representation about the device/equipment of these switches gives the given in Fig. 17-39 section/cut of the arc-suppression chamber/camera of the air-filled switch to voltage 35 kV whose general view is similar/such shown in Fig. 17-33.

The porcelain housing of 9 chambers/cameras is established/installed on collar 12. In the latter is attached also stationary contact 8 with high-melting cap. On upper collar 13 is established/installed metal housing 1, in which is placed the mechanism of slide contact 4. The latter with collar 13 is electrically connected with the aid of slipping contacts 11. For the connection of the busbars of distributor serve terminals/grippers 10 and 15. In the connected position the current flows/occurs/lasts over the path: 10-13-11-4-8-12-15.

Contact 4 is screwed into piston 2, rigidly connected with guiding tube 3.

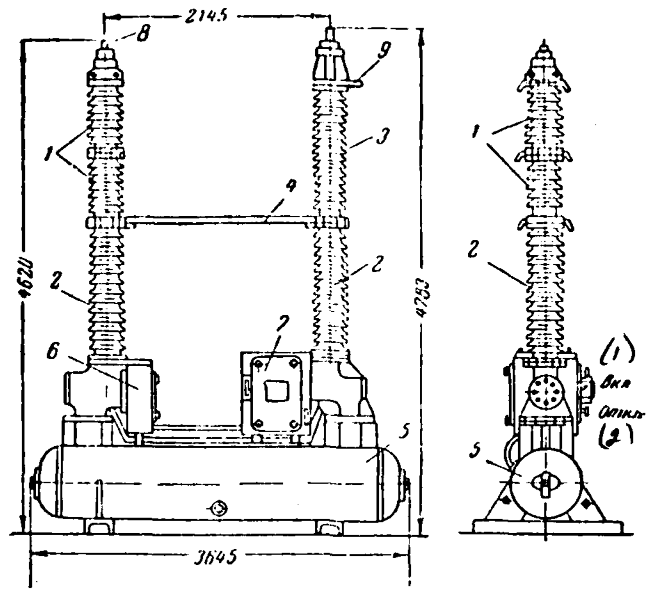

Fig. 17-38. Air circuit breaker with the air-filled separator of the type VVN-110 on 110 kV, 2000 A, 6000 MVA (one phase). 1 - arc-suppression chambers/cameras; 2 - the stand-off insulators; 3 - separator; 4 - current-carrying tube; 5 - delivery air chamber; 6 - cabinet of the cutoff/disconnection; 7 - cabinet of the start; 8 and 9 - terminals/grippers for the connection of busbars.

Key: (1). Vkl. (2). Off.

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To the latter loose piston 6 and carrier ring 5, between which is inserted spring 7. The latter through ring 5 and piston 2 forces contact by 4 against fixed contact 8.

With cutoff/disconnection housing 9 is filled with the compressed air. Along channel 14 compressed air enters space above piston 6 and it displaces it downward to backstop 17 on the internal surface of housing 1. Spring 7 is presssed.

Somewhat slower through the gap between contacts 4 and 11 air penetrates the space under piston 2 and it displaces it together with contact 4 and tube 3 upward to such situation, when ring 5 will be rested into the lower end/face of the tube of piston 6. Since piston clearance 6 is more than piston clearance 2, then during the motion of the latter together with contact 4 upward piston 6 remains forced against flange 17 and spring 7 additionally is presssed.

In this position of chamber/camera contacts 4 and 8 are located at a distance, most favorable for an arc extinction. The formed on them arc by the flow of the compressed air, which was fixed inside contact 4 and tube 3, is injected inside contact 4, intensely it is deionized and rapidly it goes out (with arc extinction occupies the position, shown on outline a Fig. 17-31).

In piston 6 is small opening/aperture 18, through which the compressed air comparatively slowly penetrates the space between pistons 2 and 6. To the time of extinguishing of arc the pressure from both sides of piston 6 is equalized and it under the action of compressed spring 7 is moved upward to backstop. Since in this position air pressure on piston 2 and contact 4 proves to be more than the force of spring 7, then simultaneously with piston 6 they are upward displaced piston by 2 with contact 4 and tube 3, until the latter is rested into rubber ring 16 and with its base 19 is shut output to the compressed air from chamber/camera. In this position the contacts prove to be dilute up to such distance, with which in the compressed air is provided the necessary insulation of gap.

For the start of switch it suffices to let out the compressed air from chamber/camera in the atmosphere. Then under spring effect 7 contact 4 is dropped/omitted to contact with contact 8 and circuit will be connected.

The air-filled switches have simplest construction/design, since in them there are no separators with the pneumatic drives, do not have insulating rods and series/row of other parts, available the switches with separators.

Main disadvantage in the air-filled switches - need for the very

good hermetic sealing/pressurization/sealing of chamber/camera, since on leaving of air switch is included.

Switch simply is fulfilled also with several gaps in phase. In the presence of backs-out resistor the switch must be equipped with the trailing contacts, intended for the gap of current, which takes place through backs-out resistor after arc extinction in arc-suppression device/equipment.

Air circuit breakers with transverse air blast.

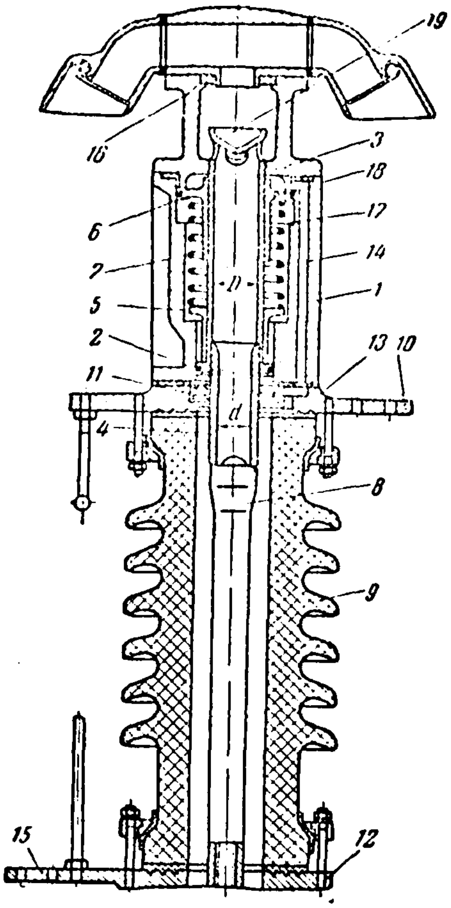

Fig. 17-39. The extinguishing chamber/camera of the air-filled switch on 35 kV.

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Transverse air blast in high-voltage switches proves to be effective,

as noted in Chapter 13, only during the use/application of arc-suppression gratings with the insulating plates, situated perpendicular to the axis of arc (Fig. 13-5c and 17-41), when airflow forces arc against the foundation of these plates and forces it into the narrow gaps/intervals between them.

The presence in the arc gap of the insulating plates, subjected to the effect of arc, impedes the creation of the necessary insulation of gap with very high voltages and especially in the switches of external installation. Furthermore, in the chambers/cameras of transverse blast arc extinction is reached at its sufficient length, as a result of which in the process of cutoff/disconnection in arc gap is separated/liberated a large quantity of heat, which impedes arc extinction and achievement of the large power of cutoff/disconnection. Therefore arc-suppression chambers/cameras with transverse blast apply in air circuit breakers by voltage to 15-20 kV and less frequently to 35 kV.

In Soviet practice transverse air blast is used in switches of the type VV-15 in voltage 13.8 kV and power of cutoff/disconnection 2000 MVA, intended for internal installation (Fig. 17-40).

The trolley of 1 switches is performed as one whole with two cylindrical delivery air chambers 2 and 3 and cabinet 4, in which are

placed the mechanisms of control of the switch: shaft 5, pneumatic drive 6, the block of control valves of 7, oil dashpot 8, blast valve 9 and 10 types blocking contacts KSA.

Arc-suppression chamber/camera 25 is established/installed on porcelain stand-off insulators 14 and 15. Air into chamber/camera is fed/conducted through valve by 9 on porcelain air duct 20.

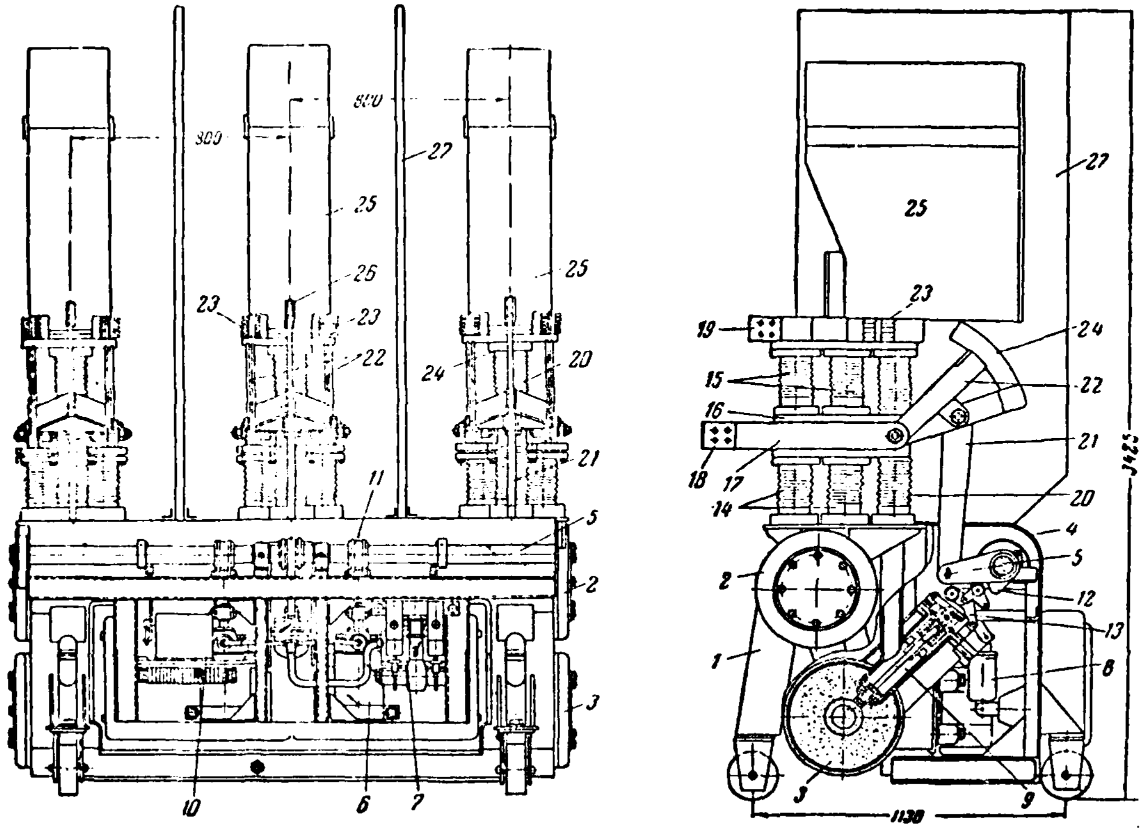

Fig. 17-40. Air circuit breaker of the type VV-15 on 13.8 kV, 5500a, 2000 MVA.

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Between insulators 14 and 15 is established/installed aluminum housing 16, from both sides of which it is attached on the packet of

copper bands 17. To the left side of these bands connect the busbars of distributor (terminal/gripper 18). In the right side between the packets of bands on axis are established/installed the slide contacts of the switch: two working knives 22 and one arc-suppression knives 24, connect/joined together and connected with insulating thrust/rod by 21 with homing/driving lever on shaft 5. Working knives are placed from both sides of housing 16. Two groups of motionless working finger contacts 23 are established/installed from both sides of chamber/camera 25. Moticnless arcing contact is located within chamber/camera 25. All motionless contacts are electrically connected with second terminal/gripper by 19 for the connection of busbars.

Between the phases of switch are established/installed insulating partitions 27. Upon the start of switch pneumatic drive 6 with the aid of leverage 11 turns shaft 5 clockwise and thrust/rod by 21, being moved upward, turns slide contacts in opposite direction. Arcing contacts 24 enter through opening/aperture 26 into arc-suppression chamber/camera and throw in themselves in the established/installed in it motionless arcing contacts. With certain retardation are closed both pairs of make contacts 22 and 23. Before closing/shorting of arcing contacts jaw/cam/catch 12 on shaft 5 through mechanism 13 presses on the stock/rod of blast valve 9 and a little opens slightly it, as a result of what the compressed air from reservoir 3 on air duct 20 enters explosion chamber and blows the

gap/interval between the convergent arcing contacts. By this is prevented the onset of powerful/thick arc upon the inclusion of switch to the existing in network/grid short circuit.

In switch is used the pneumatic drive of two-way action; therefore with cutoff/disconnection all moving/driving parts of the switch are moved in opposite direction and contacts 22 and 24 are turned in the direction of rotation of hour hand. Are first broken make contacts 22 and 23, also, after they are radiated on 30-35 mm, are broken arcing contacts. Is somewhat earlier than this moment/torque jaw/cam/catch 12, rotating together with shaft 5 counterclockwise, with the aid of mechanism 13 is opened/disclosed blast valve 9 and air on air duct 20 it enters arc-suppression chamber/camera.

The device/equipment of arc-suppression chamber/camera is schematically shown in Fig. 17-41.

To the arc-suppression knife of 24 is welded cap 28 of the refractory metal; 29 and 30 - motionless arcing contacts.

Chamber casing 25 is made from external getinax 31 and 32 and internal fiber 33 plates. Within chamber/camera is established/installed five fiber plates 34, which divide the internal

space of chamber/camera in six sections. Fiber is utilized as gas-generating material. In each section are established/installed copper plates 35, cutting the arc into parts, which contributes to its cooling and deionization and limits its length.

In the upper part of the sections are placed packets 36, collected from thin steel sheets with the small distance between them, intended for cooling and deionization of air, that emerges from chamber/camera.

As noted above, up to the moment/torque of interrupting the arcing contacts into chamber/camera has already been supplied the compressed air. Therefore the arc, which is formed between contact 30 and cap 28, which are broken by the latter, by the jet of the compressed air immediately is injected into the first section of the chamber/camera where it is contacted with fiber plates. Under the action of the high temperature of arc from the surface of fiber plates violently are separated/liberated the gases, which attempt to reject/throw arc from plates, but this blocks the cross flow of the compressed air, which emerges from air duct 20. As a result of this combined effect of air and gas flow the arc energetically is deionized and rapidly it goes out.

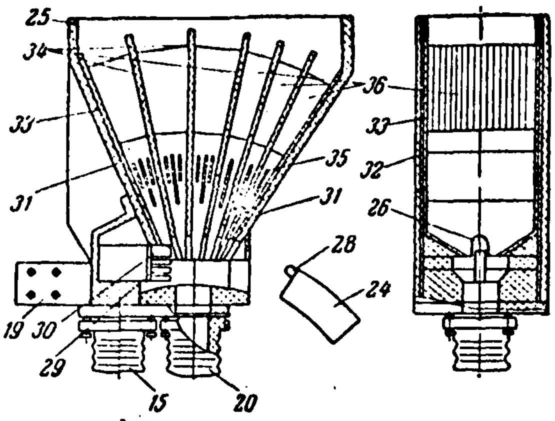

Fig. 17-41. The arc-suppression chamber/camera of air circuit breaker of the type VV-15 (is continued the numbering of the parts of Fig. 17-40).

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If arc did not go out with the passage of arcing contact under the first section, then during further motion of contact 24 arcs are blown out into the second section, while if it does not go out also in this case, then into the third section and, etc.

Up to the moment/torque of the output of arcing contact from chamber/camera the arc compulsorily goes out also in the specific position of slide contacts the air supply into chamber/camera automatically ceases.

The distance between contacts in off position is determined by the value of the necessary insulating gap/interval between them.

Fiber plates are abraded unevenly, since sections enter in work gradually and most frequently not all. By this is explained the different thickness of the plates of chamber/camera. Usually switch is capable to five times to disconnect without the exchange of fiber plates current, close to its rated current of cutoff/disconnection [17-5].

The tripping time of switch does not exceed 0.1 s with the time of the arc extinction of the order of two half-periods.

The foreign constructions/designs of air circuit breakers are characterized by very great variety also during recent years underwent considerable changes. Some of them have much in common with the examined above Soviet constructions/designs.

If in air circuit breakers to voltage to 15-20 kV widely are utilized spark extinguishers with transverse and longitudinal blast, in the latter case with external separators and without them, then in switches by voltages 35 kV it is higher, as a rule, is applied

longitudinal air blast with multiple break of circuit.

Characteristic for contemporary air circuit breakers by voltage 35 kV and higher is the wide application of cheaper and more reliable small/miniature porcelain [17-1, 17-5 and 17-6]. In recent years some European firms created very compact and light suspension air circuit breakers, suspended to the portals of the open distributors. In the form of an example in Fig. 17-42 it is shown voltage 150 kV and power of cutoff/disconnection 7500 MVA. Arc-suppression chambers/cameras 1 and 2 are established/installed directly on delivery air chamber 3, which is located under voltage and is suspended/hung to support from string insulators 4. Intake electropneumatic valves are established/installed on reservoir. The compressed air from blowing plant comes along tube 5 of insulation (porcelain or plastic).

The transmission of control signal to electropneumatic valves is realized with the aid of pneumatic or oil-pneumatic devices/equipment with the use of second tube 5.

Suspension switches separators do not usually have and are fulfilled as air-filled. They are structurally/constructurally simpler, 3 times and more more easily and it is considerably cheaper than air circuit breakers with the separators; in distributor they occupy little place [17-4].

Blowing plants. Air circuit breakers are supplied with the compressed air from central blowing plant, which can be used also for the compressed air feed of the pneumatic drives of disconnectors and switches of other types.

The schematic diagram of blowing plant is given in Fig. 17-43. A number and the productivity of compressors select so that during the damage of one compressor the supply with air would not be disrupted. In the diagram are conditionally shown two compressors 1.

The air, which enters air circuit breakers, must be well purified from dust and dried. For dusting serve filters 3, established/installed from the side of the suction branches of compressors. They dry air usually thermodynamically. Using this method the highly-compressed in compressor air which in this case considerably is heated, is cooled in water tubular coolant 4, as a result of which the large part of the containing in air moisture is condensed. This condensed moisture, and also caught into air oil are driven out in oil and water separator 5, and into high-pressure bottle by 8 enters air with smaller moisture content (6 - check valve; 7 - shutoff valve). Then air passes through reduction valve 9, where its pressure decreases, and space respectively increases, in

consequence of which relative atmospheric humidity decreases. As a result of entire this relative atmospheric humidity in low-pressure reservoir by 10 and in distributive aerial network proves to be considerably lower than relative humidity of atmospheric air. Good results gives change of the air pressure two times.

Soviet air circuit breakers are designed for work with pressure of air 20 atm(gage), in accordance with how pressure in reservoir 8 it is taken as as the equal to 40 atm(gage), and in reservoir 10 equal to 20 atm(gage).

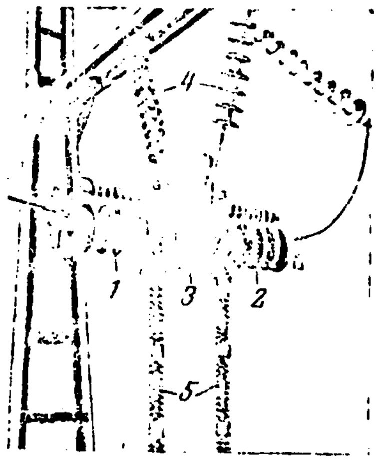

Fig. 17-42. Suspension air circuit breaker on 150 kV, 7500 MVA (one phase).

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Start and stop of the electric motor of 2 compressors is automated depending on air pressure in reservoirs, for which are utilized the established/installed on reservoirs contact manometers.

Distributive aerial network is usually performed by steel tubes. Before each switch install filter for warning/prevention the incidences/impingements into the switch of dust and products of the corrosion of tubes.

In the limits of compressor and in sections from the cable distribution heads of switches to their reservoirs and the cabinets of control usually run copper tubes for warning/preventing their corrosion.

The tubes of aerial network usually run in cable tunnels or channels, and sometimes in special channels or trenches.

17-6. Switches of load.

The switches of load are the simplest high-voltage switches, intended for cutoff/disconnection and start of circuits, that are located under load. The arc-suppression devices/equipment of these switches are designed only for the extinction of the low-current arc, which appears with the cutoff/disconnection of the current of load; therefore cannot be utilized them for the cutoff/disconnection of circuits during short circuits.

For the cutoff/disconnection of circuits during short circuits together with switches the loads apply any high-voltage safety devices/fuses, for example, quartz.

In recent years the switches of load obtained very large use/application in those installations of comparatively small power

(on shop, urban, agricultural and other substations), where it is possible to be restricted to protection from short-circuit currents with the aid of safety fuses and where the switches were necessary only for start and cutoff/disconnection of circuits with load.

The switches of load even taking into account high-voltage safety devices/fuses are less expensive and usually require less than the place in distributor, rather than powerful/thick high-voltage switches to the same voltages.

As arc-suppression devices/equipment in the switches of load can be used arc-suppression chambers/cameras with oil filling, chambers/cameras with solid gas-generating material, arc-suppression gratings with metallic or ceramic plates, etc.

Can be used auto-pneumatic chambers/cameras with arc extinction by the air, forced during cutoff/disconnection by the piston, powered by special spring. Upon the start of switch this connected with piston spring is presssed and in the compressed state is held by special trip. At the moment of cutoff/disconnection the trip is displaced and the freed spring rapidly moves piston within the cylinder, from which the compressed air is forced to arc and extinguishes it.

At present with Soviet industry are manufactured the switches of load only on voltages 6 and 10 kV, equipped with arc-suppression chambers/cameras with inserts/bushings from organic glass.

As the basis of the construction/design of these switches of load of the type VN-16 is assumed normal tripolar disconnector for internal installations (Fig. 17-44) with attached arc-suppression chambers/cameras 5 and disconnecting springs 6.

The movable make contact of switch is performed in the form of two-band knife 1, which encompasses in the connected position contact strut 2. At the end/lead of the bands of knife are attached two curved steel strips 3, between which is jammed the end/lead of arc-suppression knife 4.

The housing of explosion chamber (Fig. 17-45) consists of two jaws 5, made from plastic and tightened by screws/propellers. Within housing are laid two inserts/bushings 8 of organic glass, which form narrow slot 9.

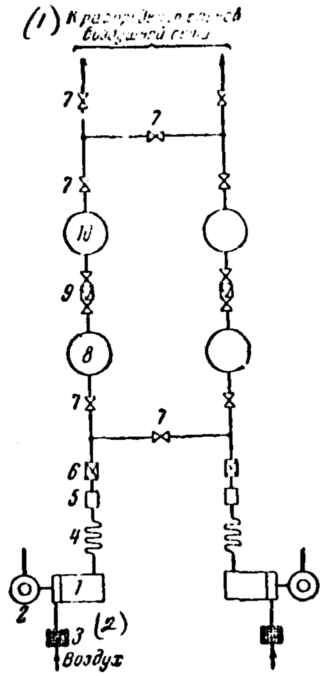

Fig. 17-43. Schematic diagram of blowing plant.

Key: (1). To distributing aerial network. (2). Air.

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Housing and motionless make contact 2 are fastened/strengthened to the cap/hood of stand-off insulator.

Motionless arcing contacts 7 are attached on steel springs and are connected by flexible members with current-carrying plate 2.

Upon start knife 4, fastened/strengthened to plates of working knife, enters into slot 9 (Fig. 17-45) explosion chamber and throws in itself into motionless arcing contacts 7. Make contacts 1 and 2 are closed later than arc-suppression ones.

With cutoff/disconnection first are broken the make contacts, and then arc-suppression, between which is formed the arc. Arc is involved/tightened inside slot 9 between inserts/bushings from organic glass. Under the action of the high temperature of arc organic glass separates/liberates a large quantity of gases, in consequence of which the pressure in chamber/camera is raised. Thus far knife 4 is located in chamber/camera, gases can leave it only through the gaps between the knife and inserts/bushings. The pressure increase increases the thermal conductivity of gases, in consequence of which the arc intensely is cooled and goes out in limits of chamber/camera, to the cutput from it of knife 4. The necessary rate of the motion of contacts is provided by two disconnecting springs 6.

The disconnecting ability of the switches of load of the type VN-16 is shown in Table P-15.

For the purpose of savings are manufactured also the combined

apparatuses of the type GNP-16, which consist of the mounted on the overall frame of the switch of load and three quartz safety devices/fuses. The analogous combined apparatus, but additionally equipped with device for the automatic cutoff/disconnection of the switch of load with burn-out by smelting the insert of any of the quartz safety devices/fuses, has a designation of the type GNP-17.

For control of switch is applied manual rigging, which has the built-in electromagnet, which makes it possible if necessary to produce remote cutoff/disconnection. If is necessary remote switching, then can be used electromagnetic actuator.

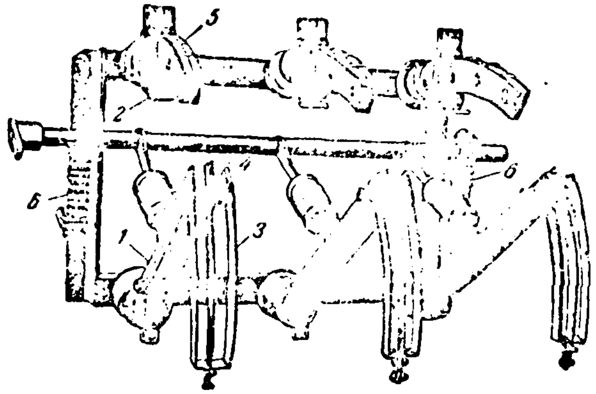

Fig. 17.44. Switch of load of the type VN-16 on 10 kV.

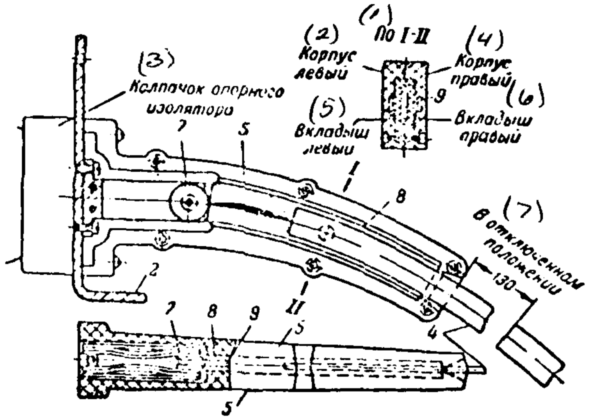

Fig. 17.45. Arc-suppression chamber/camera of switch of load of type VN-16.

Key: (1). On. (2). housing (left. (3). Cap/hood of stand-off insulator. (4). housing (right. (5). Insert/bushing (left. (6). Insert/bushing (right. (7). In off position.

Chapter eighteen.

DRIVES OF SWITCHES.

18-1. Designation/purpose and types of drives.

Drives serve for control of switches, i.e., for their inclusion, retention in the connected position and cutoff/disconnection. Drives are performed in the form of the separate apparatuses, attached to switches.

Some switches can be applied with different drives. The corresponding indications are given in catalogs or plant informational materials (see Tables P-14, P-15 and P-16).

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From drive to the slide contacts of switch the motion is transmitted with the aid of the drive mechanism, which consists of the linkage and thrusts/rods, shaft of switch and contact crossheads, which carry slide contacts.

Some switches have the built-in drives, which

structurally/constructurally compose with them one whole. Such switches are supplied only with one type of drive. In some air circuit breakers of drives as there are no separate apparatuses and the mechanisms, which use for control of switch, it is organically decanted with the construction/design of switch itself.

Drives must satisfy the following fundamental requirements: the reliability of operation, the speed of action, the ability to perform the specific number of process/operations without the need of controlling the mechanism, simplicity of construction/design, small overall sizes and weight, small cost/value, convenience in the operation. Drives with electrical control must consume with process/operations least possible power and smoothly work with the established/installed limits of deviation from the nominal voltage of their power supply. Heating the elements/cells of the drive of the magnet coils, electric motor) for the operation time must not exceed rating value.

All drives have mechanisms of the free release about value of which it was shown into §15-2.

Punishment drive completes upon the start of the switch when it overcomes the considerable resistor/resistance of the disconnecting springs and springs of contacts, friction in the mechanism of switch

and in transmission from drive to switch, in oil breakers - the resistor/resistance of oil to the motion of the moving elements of switch, etc. Upon the inclusion to the existing in network/grid short circuit the drive overcomes also the considerable electrodynamic forces (proportional to the square of impact short-circuit current), appearing after breakdown across gap between contacts in the process of their approach and caused by interaction of current in the movable and motionless current-carrying parts of the switch (these forces attempt to reject/throw slide contacts to off position).

At the same time switch must be included rapidly, since upon the slow inclusion to the existing in network/grid short circuit is possible the sticking of contacts.

Thus, upon start drive must complete considerable work in short time, i.e., it must develop the sufficiently large power whose value depends on the type of switch.

In contrast to this with cutoff/disconnection the drive completes the very small work, spent on the release of locking mechanism, since the cutoff/disconnection of switch occurs under the action of its disconnecting springs. The time of the release of locking mechanism also must be possibly less, since on this depends the speed of the cutoff/disconnection of circuit during damages.

Are distinguished two basic groups of the drives of the switches: manual and power (engine). Depending on the form of the energy, utilized for start, the actuators are subdivided into electrical ones and pneumatic ones.

Depending on the principle of the conversion of electric power into mechanical energy the electric drives occur electromagnetic (solenoid) and electric-motor.

On method of operation the drives are subdivided into the drives of direct and indirect action.

In the drive of direct action the motion of switching on actuator is transmitted to the directly drive mechanism of switch to the same moment/torque when drive obtains the impulse/momentum/pulse of energy from its feeding source (from electrical circuit, from the main line of the compressed air). Since the time of start is small, then the power, consumed by such drives, is considerable.

In the drives of indirect action the energy, necessary for the inclusion of switch, preliminarily reserves itself in the form of potential or kinetic energy in any special device/equipment, which

then at necessary moment/torque is utilized short-term for the start of switch. Potential energy reserves itself in cargo drives with the aid of the preliminarily raised load and in spring drive with the aid of the preliminarily stretched or twisted springs.

Kinetic energy reserves itself in inertial drives with the aid of the preliminary untwisted to the definite rate flywheel of considerable mass.

In the drives of indirect action the energy reserves itself during relatively long time (to 10 s); therefore the required by them power is respectively small.

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The stored up energy is utilized upon the start of switch for the very short time when mechanism develops large power.

For the automatic cutoff/disconnection of switches all drives have the disconnecting electromagnets, which affect locking actuator, made in the form of retaining catch or system of the breaking levers. The circuit of the coil of the disconnecting electromagnet of drive is closed by the contacts of the relay of protection or automation. In some drives the disconnecting electromagnets can be used for the

remote (at a distance) cutoff/disconnection of switches.

All electrical and pneumatic drives, and also load and spring drive make it possible to remotely control of switches i.e., to switch on and to disconnect them at a distance.

Drives are manufactured for internal and external installation. For protection from weather effects the drives for external installation are placed into metallic cabinets, which in a designation of the type of drive is characterized by letter Sh. For example: PE - drive electromagnetic for internal installation ShPE - the same drive, but built in the cabinet and intended for external installation.

18-2. Hand drives.

In hand drives for the start of switches is utilized the muscular force of man. These drives have simple and fail-safe design, are cheap, simple in operation and for their work either in no way they are required the special sources of operational current, for example storage batteries or can be used the low-power sources of the direct or alternating current (for greater detail, see Vol. 2, Chapter 11).

Hand drives are the drives of direct action; therefore their use/application is limited to switches with the small moment/torque of start - with effort/force on handle or handwheel of drive not more than 25 kgf. The use/application of hand drives on oil bulk-oil breakers is possible only in such a case, when impact short-circuit current in the site of installation of switch does not exceed 30 kA, since with the larger current of too considerable proves to be the electrodynamic force, which appears upon the inclusion of the switches indicated to the existing in network/grid short circuit and which blocks their start. These limitations in the use/application of hand drives are caused by the fact that with the large efforts/forces, necessary for the start of switch, man either not at all will be able him to include/connect or it will him switch on slowly, which upon start to short circuit is conjugated/combined with the danger of welding the contacts of switch.

There are many different constructions/designs of hand drives. Earlier are very common were common drives of the type KAM (case automatic flywheel). At present Soviet plants manufacture the manual automatic drives of types PRA (drive manual automatic) and PRBA (B - blinker). Indication about that, with what switches it is possible to apply these drives, they are given in Table P-14.

The appearance of drive of the type PRBA is shown in Fig. 18-1.

Actuator is built in cast iron housing 1, closed with cover/cap 2 with groove for lever of control of 3. Thrust/rod by 4 connects actuator with the switch (see Fig. 17-15). In relay case 5 are built in overload relay 6 and low-voltage relay 7. Drive is shown in the connected position of switch. In off position the control handle occupies position 3'.

Signal relay (lever) 8 serves for the signaling of the automatic cutoff/disconnection of switch.

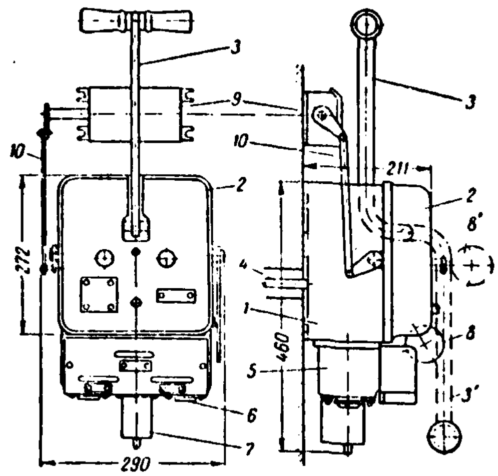

Fig. 18-1. Manual automatic drive of the type PRBA.

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With the automatic cutoff/disconnection of switch signal relay 8 occupies horizontal position 8' (is utilized nonconformity in the position of actuator and control lever - switch was disconnected, but lever 3 remained in engage position). In order to drop/omit signal relay, it is necessary lever 3 to turn to position 3'.

9 Types blocking contacts KSA are connected with actuator with thrust/rod by 10.

Different positions of actuator are shown in Fig. 18-2. Control lever 1 and rigidly connected with it disk 18 can freely rotate on axis O_1. The connection/communication of lever 1 with thrust/rod to switch 11 is realized with the aid of thimble 3 and main lever 2. On the latter there are plug 4, employee by axis of his rotation, which can be moved in horizontal slot 16, carried out in the struts of the bracket, on which is attached entire actuator within its housing. To this plug 4 loose trip 5, hinged connected with thimble 19. Thimble 19 and lever 6 are mounted to fixed axis O_2.

In the connected position of switch (position a) its springs attempt to turn lever 2 clockwise (on axis 4). This blocks that that axis 8, which connects thimble 3 with control lever 1, is located beyond dead center, i.e., below straight line ab, which connects the centers of axes a and O_1. The displacement of axis 4 is also impossible, since trip 5 rests into the semi-axis of 6' levers 6. The butt end of the latter rests into the finger/pin of disconnecting plank 7, by restoring spring 14.

With automatic cutoff/disconnection the shock worker of 10 disconnecting electromagnets rests in the finger/pin of plank 7 and turns it counterclockwise. In this case lever 6 is freed/released and

under spring effect 15 is turned counterclockwise. Semi-axis 6' will move away it to the left and frees/releases trip 5. As a result is freed/released axis 4 and main lever 2 - switch is disconnected. Entire linkage occupies the position, depicted in the diagram 6 (plug 4 is moved it to the left and occupies position 4').

With manual cutoff/disconnection they revolve control lever 1 clockwise. Together with it rotates disk 18, which turns to small angle frictionally connected with it lever 13, freely mounted to axis O_1 (17 - screw/propeller for controlling the spring of friction coupling). The butt end of lever 13 rests in the finger/pin of disconnecting plank 7 and turns it. Lever 6 is freed/released, and switch is disconnected. Further motion of lever 1 downward occurs with off switch.

It is not difficult to be convinced that the automatic cutoff/disconnection occurs also in such a case, when we long hold by hand lever 1. Linkage 3-2-5-19-6 forms the mechanism of the free release of drive.

In order to include/connect switch after its automatic cutoff/disconnection, it is necessary lever of control 1 to turn downward. Together with control lever is turned disk 18, which with the aid of thrust/rod by 12 abstracts/removes lever 6 to the left. In

this case the end/lead of trip 5 goes under semi-axis 6', and the butt end of lever 6 will begin to fall for the finger/pin of plank 7 (positions c and d).

In drives with built-in low-voltage relay lever 1 in lower position presses on knob/button 9, with the aid of which is started the mechanism of relay (reset).

Upon start (from position d) they turn lever 1 upward.

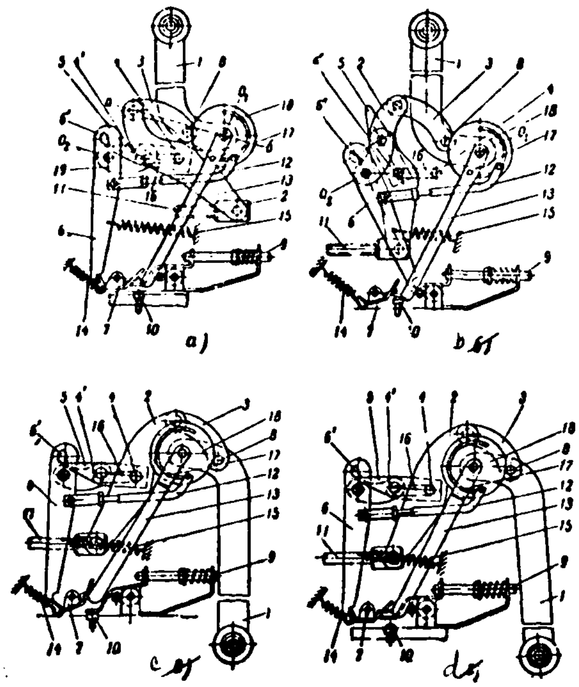

Fig. 18-2. Schematic of actuator of the type PRBA in different positions. a) is connected; b) after the automatic cutoff/disconnection; c) with the winding up of the mechanism; d) in initial position.

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Since axis 4 in this position is motionless, then by means of thimble 3 lever 2 is turned counterclockwise on axis 4 and thrust/rod by 11 is moved to the right (on drawing) - switch is included.

The appearance of drive of the type PRA is shown in Fig. 18-3. Process/operations perform by handle 1 whose plug is put on to axis 2. On the back of plug, within housing 3, are two fingers/pins, with the aid of which the motion of handle 1 through the levers of the mechanism of the free release of drive is transmitted to shaft 4, connected with the shaft of switch (as in Fig. 18-5).

Fig. 18-3 drive shows in the connected position. Disconnecting springs of switch attempt to turn shaft 4 and actuator against the direction of rotation of hour hand, what blocks retaining catch, built in the housing of drive. For a manual cutoff/disconnection it suffices to turn handle 1 to very small angle counterclockwise. In this case retaining catch is displaced and actuator with shaft 4 they are freed/released. Together with this it is freed/released and the movable system of switch - the latter under the action of its disconnecting springs is disconnected.

The mechanism of the free release of drive separates shaft 4 and plug of handle 1; therefore latter with the cutoff/disconnection of switch does not rotate. After the cutoff/disconnection of switch the operator continues to crank counterclockwise to those pores (to backstop), until occurs the cohesion/coupling the fingers/pins of the plug of handle with the levers of the mechanism of free release, but thereby also with shaft 4. Drive will be "brought", i.e., it is

prepared to start.

Upon the inclusion handle rapidly revolve in direction the rotations of hour hand. In this case pins of the plug of handle by means of the levers of the mechanism of free release revolve shaft 4 and is connected switch. Process/operation concludes, when the movable system of drive proves to be its closed trip.

With automatic cutoff/disconnection the shock worker of the core of the disconnecting electromagnet acts on retaining catch of drive which frees/releases actuator and shaft 4, after which the switch under the action of its disconnecting springs is disconnected. Lever 1 does not rotate and remains in position "connected". For the subsequent start of switch it is necessary to prepare (to bring) drive, i.e., to turn its handle counterclockwise before the cohesion/coupling of the fingers/pins of plug with the lever of the mechanism of free release.

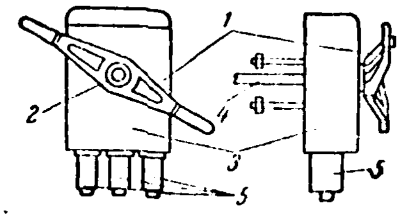

Fig. 18-3. The appearance of a manual automatic drive of the type PRA.

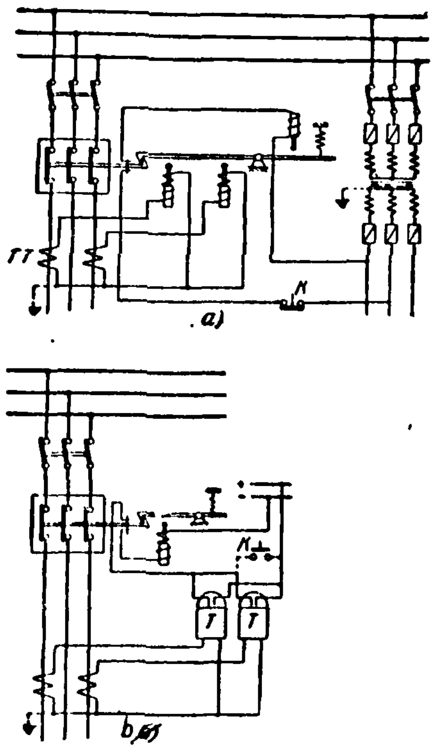

Fig. 18-4. Circuit diagrams of hand drives. a) with two built-in overload relays and one low-voltage relay; b) with one disconnecting

electromagnet and separately established/installed overload relay; K - knob/button of remote cutoff/disconnection.

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Hand drives can be equipped (in different combinations) with the disconnecting electromagnets for a work on direct and alternating current, two or three built-in overload relays of momentary effect, with one built-in low-voltage relay.

The spill current of built-in overload relays regulate by change numbers of turns of their coils. If necessary it is possible to apply relay with the mechanism of time element, making it possible to regulate triggering time in limits from 0 to 4 s (drives of the type PRA, equipped with relay with the mechanism of time element, are designated by PRAM).

Fig. 18-4 in the form of an example gives the elementary diagrams of hand drives: the diagram of drive with two built-in overload relays of momentary effect and one built-in low-voltage relay (Fig. 18-4a) and diagram of drive with one built-in disconnecting electromagnet on operational direct current and two separately established/installed overload relays (Fig. 18-4b).

By the examined manual automatic drives cannot be switched on switches remotely and automatically and this is their fundamental and very essential deficiency/lack, which limits sometimes their use/application.

18-3. Cargo and spring drive.

At present very widely automate electrical devices how is achieved a considerable increase in the reliability of the power supply of users, an increase in the efficiency/cost-effectiveness of the operation of electrical devices and the decrease of the number of service personnel.

On electrical stations and substations with light switches to comparatively low power of cutoff/disconnection (to 300-400 MVA) the problem and automatic remote control of switches most simply and cheaply is solved with the aid of hand drives of the indirect action: cargo ones and spring. The important advantage of these drives, besides the previously enumerated advantages of all hand drives, is the fact that they consume very small electrical power with the process/operations of start and cutoff/disconnection and can reliably work both on operational direct current and on operational alternating current. In the latter case is not required the construction of the battery installation (for greater detail, see

Vol. 2, Chapter 11).

With the aid of these drives can be carried out manual and remote control of switches, automatic breaking of stand-by lines, of power transformers and electric machines (AVR), automatic reset of the emergency disconnected parts of electrical devices (APV), etc.

Cargo drives. Fig. 18-5 shows the installation of manual cargo drive of the type PG-10 on an oil breaker of the type VMB-10.

Actuator, relay of protection and electromagnets of the inclusion and cutoff/disconnection are placed in welded housing 1. Through the rear wall of housing is brought out shaft 2 (drive shaft), which with the aid of clutch 3 is connected with the shaft of switch 4.

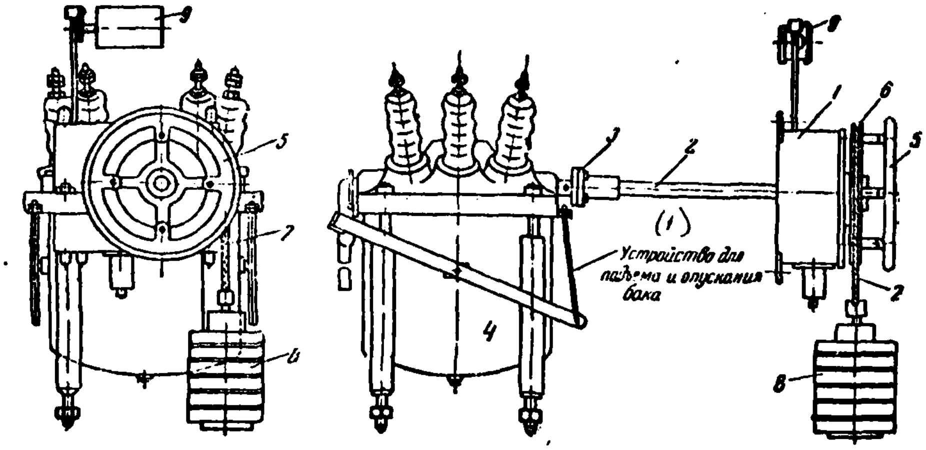

Fig. 18-5. Installation of manual cargo drive of the type PG-10 on an oil breaker of the type VMB-10.

Key: (1). Hoisting device and settling of tank.

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Within housing at shaft butt end 2 is rigidly seated the lever, called the lever of shaft.

Upon the start of switch drive shaft and its lever they turn clockwise to the angle, depending on the type of switch. In the

connected position the lever of shaft seizes retaining catch of drive, which holds thereby switch in the connected position.

For the cutoff/disconnection of switch it is necessary to compound retaining catch indicated so that it would free the lever of shaft. Then under the action of its disconnecting springs switch is disconnected. In this case shaft 2 and its lever is turned to certain angle counterclockwise. The displacement of retaining catch and the cutoff/disconnection of switch most remote possible - with the aid of the built-in the drive disconnecting electromagnet, automatic - with the aid of the built-in the drive relays or with the aid of the disconnecting electromagnet and the separately established/installed relays and manual - with the aid of the knob/arm/handle, placed from the side the housing of the drive (it is similar to knob/arm/handle 2 in spring drive, shown in Fig. 18-6).

Drive has a mechanism of free release; therefore with the cutoff/disconnection of switch handwheel 5 on rotates.

Through the front/leading cover/cap of the housing of drive is passed the second shaft of small length (shaft of the handwheel), to tetrahedral free end of which they are put on handwheel by 5 with block 6, which has groove for cable 7. One end/lead of the cable is attached on block, from other end/lead of the cable is suspended/hung

load 8. The total cargo weight depends on the type of switch and is from 18 to 55 kg. Is regulated the cargo weight by detachable circular weights.

At shaft butt end of handwheel (within housing) is mounted rocker shaft arm which with the aid of actuator is engaged with the lever of shaft 2 during the process/operation of start.

If switch is disconnected, then for its start it is necessary to preliminarily prepare (to bring) drive. For this they by hand turn handwheel 5 counterclockwise and is risen load 8 to its maximum upper position. Simultaneously within housing is turned the lever of the handwheel which in end position is cut off by the special trip, which holds load in the raised position (trip of load). Simultaneously are engaged the levers of handwheel and drive shaft. Therefore, if we now displace the trip of load and to free the lever of handwheel and load, then the latter with its incidence/drop will turn the engaged levers of handwheel and drive, but thereby also shaft 2 clockwise - a switch will be connected. At the end of the course of start the lever of shaft is seized by retaining catch of drive. Depth of fall in the load of approximately/exemplarily 450 mm.

The displacement of the holding trip of load and the start of switch is conducted remotely with the aid of special clutch magnet or

by hand via pressure the core of the same electromagnet.

From that presented it is evident that the handwheel serves only for the preparation of drive for start.

If we with the connected switch bring drive, i.e., to raise its load, then after automatic cutoff/disconnection from the relay of protection the trip of load mechanically is displaced and switch automatically is included how is realized instantaneous APV (for greater detail, see Vol. 2, Chapter 14). If necessary the device/equipment APV can be brought out from the work (with the aid of the knob/arm/handle, similar to knob/arm/handle 2, shown in Fig. 18-6; there it is visible lever 3, which indicates, does work drive with APV or without APV).

The examined cargo drives are applied for the same switches, as usual hand drives. The electromagnets of drive consume the power not more than 300-500 W. Depending on the type of switch the time of start is 0.2-0.35 s.

A deficiency/lack in these drives is the need for their manual preparation for start.

The more advanced construction/design is drive of the type

PGM-10, in which is provided supplementary device/equipment for the power elevation of load after each functioning of drive for the start of switch. This device/equipment consists of the electric motor of direct or alternating current by the power of 50-100 W, worm reducer, toothed gears and terminal switches.

After the start of drive special roller on block closes terminal switch, which switches on electric motor. The latter with the aid of reducer and gears turns handwheel and is risen load. Near the end upper position of load terminal switch is disconnected and interrupts/breaks the feed of electric motor.

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But at this moment drive is already brought and is held by the trip of load, i.e., it is ready to the subsequent process/operation of start. The automatic preparation of drive lasts not more than 6-10 s.

Spring drives differ from the dismantled/selected cargo drives at the fundamental the fact that in them instead of the load is used the steel helical spring, built in the rim of handwheel (Fig. 18-6). For the start of switch it is necessary to preliminarily bring spring, after turning handwheel to the specific angle.

In drives of the type PP-10 the spring can be brought only by hand, with the aid of handwheel.

In drives of the type PPM-10 is a built-in low-power electric motor (as in cargo drives of the type PGM-10), which makes it possible to tighten up a spring not only by hand, but also it is remote or automatically after each start of switch (Fig. 18-6).

In other respects mechanism of spring drive it is arranged analogously with the mechanism of cargo drives. Certain improvement of the parts of spring drive makes it possible to apply them under conditions of the large frequency of process/operations, for example in electric furnace installations.

Knob/arm/handle 2 (Fig. 18-6) serves for the manual cutoff/disconnection of switch. Lever 3 is indicator, connected or not device/equipment of instantaneous APV (see above description of cargo drive).

With manual lever/crank spring drive some of different construction/design are supplied gas-generating switches of the type VG-10, briefly described into §17-4. These drives compose one whole with switches.

Spring drive can be carried out, also, for control of heavy switches to the large power of cutoff/disconnection. These drives are supplied with several strong springs which can be stretched only with the aid of the built-in electric motor. Soviet plants such drives do not manufacture.

18-4. Electromagnetic actuators.

Electromagnetic actuators can be prepared for and automatic remote control of any, switches. The schematic diagram of the device/equipment of simplest electromagnetic actuator is given in Fig. 18-7. Basic parts of drive are switching on 1 and disconnecting 3 electromagnets and retaining catch 5. The core of 2 clutch magnets is connected with the aid of thrust/rod by 6 with lever 7, mounted to the shaft of 8 switches.

With cutoff/disconnection the core of 4 disconnecting electromagnets strikes into the long arm of trip 5, the cap of the latter slips from core 2, after which the switch under the action of its disconnecting springs is disconnected.

For start close circuit the coils of clutch magnet 1, after which its core 2 is pulled and by means of thrust/rod by 6 turns lever by 7 on the shaft of switch. Switch is included; in the

connected position entire system is held by trip 5.

As a result of the direct connection of core 2 with the shaft of switch with the aid of thrust/rod by 6 and lever 7 drive does not have free release. In drives without the free release: 1) switch cannot automatically be disconnected from the relay of protection, if core 2 mechanically was wedged or "sealed" within coil or if the about latter on any reasons long flows current.

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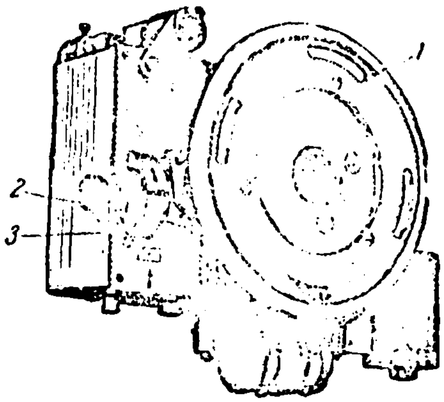

Fig. 18-6. Spring drive of the type PPM-10 with the self-starter of spring.

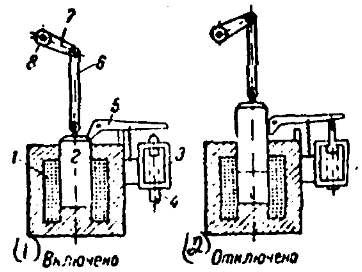

Fig. 18-7. Diagram of electromagnetic actuator.

Key: (1). It is connected. (2). It is disconnected.

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2) the mechanical and magnetic retardation of core 2 during its

motion within the coil of clutch magnet with the cutoff/disconnection of switch considerably increases the time of its cutoff/disconnection; 3) automatic cutoff/disconnection is possible only after switch completely was included/connected, since only after full/total/complete start switch ceases the feed of electromagnet 1, which also increases the time of the automatic cutoff/disconnection of switch.

On the reasons indicated all electromagnetic actuators perform with the mechanisms of free release, which ensure the release of the core of clutch magnet with transmission to the shaft of switch during its cutoff/disconnection. By this it is provided: 1) the automatic cutoff/disconnection of switch with the long sucked core of clutch magnet; 2) independence with the cutoff/disconnection of the motion of the drive mechanism of switch from the return of the core of clutch magnet in the initial position; 3) automatic cutoff/disconnection on the larger part of the course of start, i.e., it is earlier, rather than switch completely will be included/connected.

To the advantages of electromagnetic actuators should be related simplicity of their construction/design, small cost/value and high reliability of operation.

Electromagnetic actuators are the drives of direct action; therefore their clutch magnets consume very large current - ten and hundreds of amperes. This is main disadvantage in electromagnetic actuators.

The disconnecting electromagnet consumes small current, usually several amperes.

Electromagnetic actuators normally are constructed for a work on direct current. Therefore in the installations, equipped by electromagnetic actuators, it is necessary to have sufficiently powerful/thick storage batteries for their feed. Furthermore, is necessary the separator of power cables of sufficiently large cross sections for the feed of drives.

Electromagnetic actuators on alternating current have large sizes/dimensions, their construction/design is more complicated, cost/value is above. Is more current at the moment of start. The advantage of the drives of alternating current in the fact that for their work is not required the installation of powerful/thick storage batteries.

Possibly also the use/application of drives of direct current with feed by their rectified current (see Vol. 2, Chapter 11).

The time of the inclusion with the aid of electromagnetic actuators in dependence on the type of switch is from 0.18 to 0.8 s.

Soviet plants manufacture several types of electromagnetic actuators of direct current. The majorities of the produced at present switches are supplied with the drives of types PS and PE (Tables P-14 and P-16).

Clutch magnets of drives perform on 110 and 220 V, and the disconnecting electromagnets to the same voltages or to voltages 24 and 48 V (with feed from special battery). The magnet coils of some drives consist of two parts, which makes it possible one and the same drive to apply to two voltages: with parallel connection of coils on 110 V, and with series connection on 220 V.

Fig. 18-8 shows drive of the type PS-10 (in the connected position), intended for the switches of the small disconnecting ability and by voltage not more than 35 kV, for example for the switches of types VMB-10, VMG, etc. Fig. 18-9 schematically shows actuator in different positions.

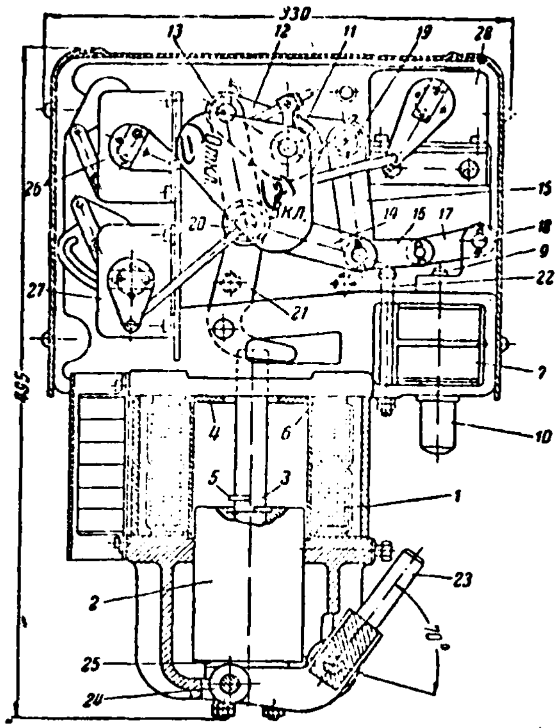

Fig. 18-8. Electromagnetic actuator of the type PS-10.

Key: (1). Off. (2). Vkl.

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Drive shaft 11 is rigidly connected with the shaft of switch. Actuator consists of the attached on drive shaft of the lever of 12, three identical connecting links (levers) 13, 14 and 15, roller 20 to axis O_1, two identical connecting links 16 and 17 the trip (backstop) of 21, equipped with spring.

Lever 12 with connecting link 13, and also all connecting links between themselves are hinged with the aid of axes O_1, O_2, O_3 and O_4. Connecting link 15 is suspended/hung from fixed axis 19; connecting link 17 also has fixed axis 18.

At the connected position of switch axis O_1 of roller 20 lies/rests on trip 21, and connecting link 16 - on backstop 22. Connecting links 16 and 17 occupy such position, that the center O_4 lies/rests below the line of centers O_4 it lies/rests below line of centers O_3 and 18, i.e., center O_4 lies/rests somewhat lower than dead center of connecting links 16 and 17. Backstop 22 blocks the displacement/movement of components/links 16 and 17 downward (see also Fig. 15-5). The disconnecting springs of switch attempt to turn

its shaft, and thereby also entire linkage of drive in the direction of rotation of hour hand. This blocks the fact that axis O_1 rests into trip 21, and axis O_3 is held by temporarily rigid linkage 15-16-17.

With remote cutoff/disconnection is closed the circuit of the coil of disconnecting electromagnet 7 (by key/wrench of control or by contacts of the relay of protection), core 8 is pulled into coil and by striker 9 it displaces upward connecting link 17. As soon as axis O_4 will pass dead center of connecting links 16 and 17, the latter break (Fig. 18-9b) and temporarily fixed link O_3 is displaced to the right. As a result of this the linkage 12, 13, 14 and 15 acquires mobility, axis O_1 of roller 20 slips from trip 21, and under the action of the disconnecting springs of switch occurs its cutoff/disconnection. Roller 20 falls downward, until it gets up against the groove, available on the internal surface of trip 21. At this moment blocking contacts 27 (Fig. 18-8) disrupt the circuit of disconnecting electromagnet 7, and core 8 falls downward, freeing/releasing connecting links 16 and 17. Under spring effect on axes 19 and O_3 (on diagrams they are not shown) actuator brings to the position, depicted in Fig. 18-9c; axis O_1 of roller 20 enters into the groove of trip 21. Drive is prepared to start.

Upon start closes circuit the coils 1 of clutch magnet. Core 2

is pulled inside the coil, seizes by stock/rod 3 roller 20 it moves it upward. Linkage 14, 13 and 12 is turned around temporarily fixed center O_3; shaft 11 is turned on the arrow/pointer of hours. With upward motion axis O_1 of roller slips on the surface of trip 21 and somewhat presses the latter to the left (Fig. 18-9d). When axis O_1 proves to be above trip 21, the latter under the action of its spring is deflected it to the right and seizes from below axis O_1, holding entire system in the connected position. At the end of the course of start blocking contacts 27 (Fig. 18-8) disrupt the circuit of the start of drive, core 2 with stock/rod 3 is supplied downward. Impact is softened by buffer rubber plates 25. Entire system occupies the position, depicted in Fig. 18-8 and 18-9a.

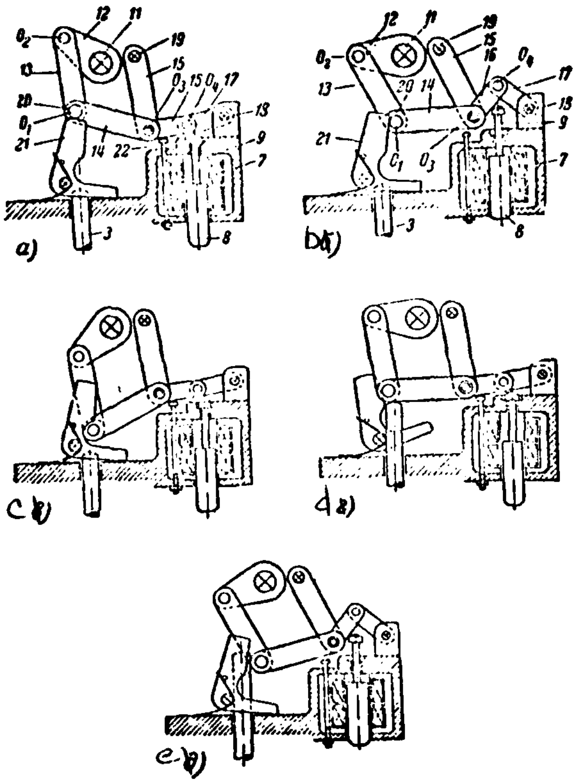

Fig. 18-9. Different positions of actuator of the type PS-10. a) is connected; b) the beginning of the cutoff/disconnection; c) is disconnected; d) at the end of the course of the start; e) the cutoff/disconnection, which follows immediately after start.

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If switch is included to the existing in network short circuit, then automatic cutoff/disconnection occurs also in such a case, when

stock/rod 3 still is found in upper position, that as under the influence of the striker of 9 disconnecting electromagnets on components/links 16 and 17 occurs the displacement to the right of hinge O_3, and roller 20 slips from the end/lead of stock/rod 3 (Fig. 18-9e). The consequently, hinged body-fixed system of motion rods provides the free release of moving part of the drive(stock/rod of clutch magnet) and switch.

Blocking contacts 26 in the feed circuit of the coil of 1 clutch magnet are adjusted so that they are closed at the very beginning of the course of the cutoff/disconnection of drive. Therefore, if automatic cutoff/disconnection from relay proceeds at moment/torque, the code the key/wrench of control is located even in position "on", then at the very beginning of the course of cutoff/disconnection coil 1 will again obtain feed and core 2 it will again prove to be pulled and besides earlier than roller 20 is occupied its lower position (stock/rod 3 can catch roller only if the axis of roller will enter into groove in trip, but in this case this will not occur, since stock/rod will be raised earlier than will be dropped/omitted the roller (see Fig. 18-9e). Therefore is removed the reclosing of switch to short circuit. Core 2 remains that sucked until closed circuit of coil 1.

Metallic cylinder 6 within coil (Fig. 18-8) shields it from

damage by core during its motion. Brass washer 4 prevents the adhesion of core to the housing of drive after the start; for the same purposes to stock/rod 3 is put on wringing out spring 5.

Manual start is possible with the aid of gas tube (l = 500-800 mm; diameter 3/4"), which is slipped over lever 23. During the rotation of lever roller 24 rises core 2 upward - occurs the start of switch.

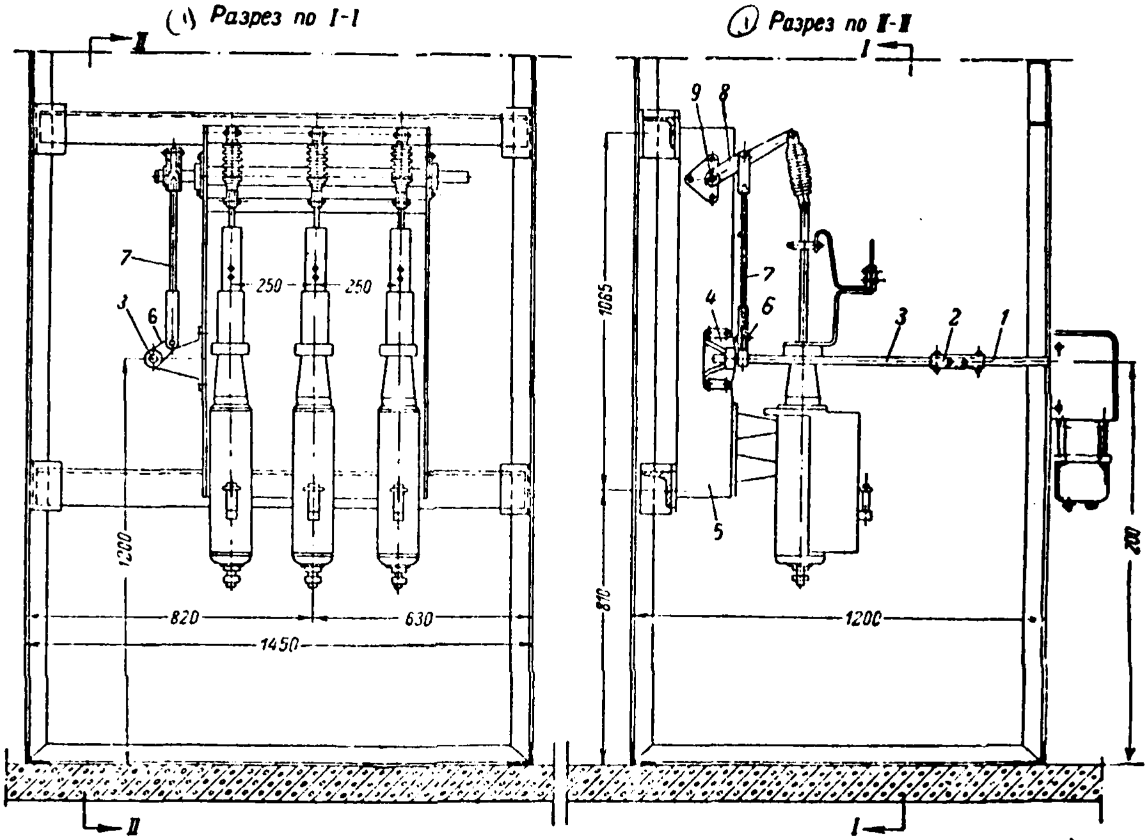

Fig. 18-10. installation of electromagnetic actuator of the type PS-10 on an oil breaker of the type VMG-133.

Key: (1). Section/cut on.

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Manual start is admissible only with testing and control of drive and

switch during mounting or repair. The operational start by hand of switch to network is inadmissible. For a manual cutoff/disconnection serves knob/button 10. Contacts 28 change over the circuit of the signal lamps (see diagram in Fig. 18-11).

In Fig 18-10 is shown the installation of drive of the type PS-10 on an oil breaker of the type VMG-133. Drive shaft 1 by clutch 2 is connected with auxiliary shaft 3 rotating in bearing 4, fastened/strengthened to the frame 5 of switch. Rocker shaft arm 6 on shaft 3 is connected with thrust/rod 7 with rocker shaft arm 8 on the shaft of switch 9. Thus, the rotation of drive shaft through the hinged connected system, which consists of lever 6, thrust/rod 7 and lever 8, is transmitted to the shaft of switch.

In Fig. 18-11 is given the simplified electrical diagram of remote control of switch with the aid of electromagnetic actuator whose mechanical feature is shown conditionally. Diagram is supplied from the storage battery through busses of control ShU, which are located on the panel of control, and busses of inclusion ShV, laid in the distributing device/equipment and intended for the feed of the circuits of clutch magnets V3 of the drives of switches.

For the closing a circuit of the switching on and disconnecting electromagnets of drive are applied the pushbutton or rotary

keys/wrenches of control. In diagram in Fig. 18-11 is shown the simplest pushbutton key/wrench of the control KU, which consists of two normally extended knobs/buttons of start V and cutoff/disconnection O.

Switch in the diagram is shown in the connected position, about which signals the burning red light LK.

With remote cutoff/disconnection by knob/button O they close the circuit of the disconnecting electromagnet OE, after which the trip Z is displaced and switch under action by disconnecting springs OP is disconnected.

Blocking contacts BK are changed over: contacts 2 and 3 are broken, but contacts 1 and 4 are closed. The circuit of electromagnet OE is broken. Red light LK goes out, and green light LZ is fired.

During short circuit in circuit it operates/wears relays T and its contacts it closes the circuit of the disconnecting electromagnet OE - switch is disconnected.

Let us examine the inclusion of switch, bearing in mind that when it is disconnected, blocking contacts 1 are closed, and blocking contacts 2 are open.

By knob/button V they close the circuit of the holding magnet of the intermediate contactor K, established/installed in distributive device and connected into circuit clutch magnet VE. Contactor K is included and closes the circuit of electromagnet VE - switch is included. Blocking contacts BK are changed over. During interrupting of the contacts 1 breaks the circuit of the electromagnet of contactor, the latter are disconnected and breaks the circuit of clutch magnet VE.

From the aforesaid it is evident that knobs/buttons V and O, and also the contacts of the relay of protection T only close the corresponding circuits, whereas the gap of these circuits is realized by more powerful/thick units by contacts 1 or 2. By these is prevented the considerable fusing of the contacts of knobs/buttons and relay.

Contactor K in the circuit of clutch magnet is established/installed in order not to load the key/wrench of control of the high current, consumed by this electromagnet, or to avoid the cable laying of large cross section from control board to drive.

Another electromagnetic actuators of types PS and PE (table

P-16) have some design differences from the dismantled/selected drive of the type PS-10, but in them is also provided mechanical interlock for peventing reclosing of switch in the case of its automatic cutoff/disconnection at the moment/torque when the key/wrench of control remains even in position "on".

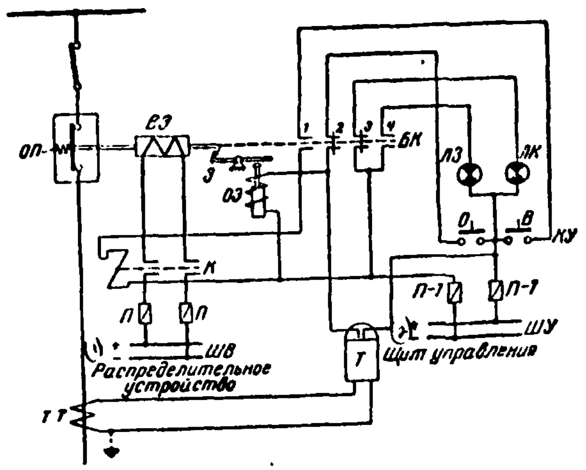

Fig. 18-11. The simplified circuit of control of an electromagnetic wire of the type PS-10. V - knob/button of connection; O - knob/button of the cutoff/disconnection; LK - tube red; LZ - tube green; BK - blocking contacts; VE - clutch magnet; OE - disconnecting electromagnet; Z - trip; K - contactor; P and P-1 - safety devices/fuses; ShU - busses of control; ShV - busses of start.

Key: (1). Distributor. (2). control board.

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Drives of the type PS-30 do not have mechanical interlock indicated; therefore in the diagrams of their control is provided for appropriate electrical interlock (see Vol. 2, chapter 16).

18-5. Electric-motor drives.

Electric-motor drives can be direct and indirect action. An example of the electromotive drive of direct action is the centrifugal drive whose schematic diagram is given in Fig. 18-12. Engine rotates the linkage, made in the form of parallelogram with loads. under the action of centrifugal force the loads diverge, parallelogram is presssed and carries along downward the thrust/rod, which transmits motion to the shaft of switch. In the connected position entire system is held by the trip, not shown in the diagram. After the termination of start the electric motor automatically is disconnected from network. Centrifugal drive is supplied with the mechanism of free release.

Centrifugal drives can be supplied with the electric motors of direct or alternating current.

Their main disadvantage as all drives of direct action, is the consumption of large making capacity. Structurally/constructurally they more complicated than electromagnetic actuators, more expensive than the latter require more careful drift/care.

In the USSR centrifugal drives were previously manufactured with plant "electrical device" (type PVM) for very heavy switches 220 kV of the type MKP-274.

An example of the electric-motor drive of indirect action is inertial drive. In this drive the electric motor untwists the sitting to its shaft of flywheel, after which the stored up in flywheel kinetic energy is expended/consumed on the start of switch. Starting process following. From the panel of control first start the electric motor of drive, which turns/runs up massive flywheel during about 10 s. On the achievement by the engine of the normal rotational speed are closed the contacts of the connected with shaft engine of centrifugal relay and on control board is fired the signal lamp, which indicates that the drive is ready to action. At necessary moment/torque the person, who generates process/operation, closes by the key/wrench of control the circuit of the coil of the engaging device/equipment, short-term connecting handwheel shaft with transmission to the shaft of switch. Simultaneously is disconnected supply of engine. After the termination of start the engaging device/equipment indicated automatically returns to initial position. Drive is equipped with the mechanism of free release and with the disconnecting electromagnet.

The power of electric motor is only 0.3-0.5 kW, what is the

major advantage of inertial drive.

In the USSR inertial drives were previously manufactured with plant "electrical device" (type PI).

~~1~~6. The pneumatic drives.

In the pneumatic drives the switch is included by the compressed air, which enters from the special reservoirs, filled by air from central blowing plant. By basic parts of drive (Fig. 18-13) they are cylinder 1 with piston 2 whose stock/rod of 3 with the aid of the mechanism of free release is connected with the shaft of switch. Upon start is opened/disclosed electropneumatic valve 5, through which the air from reservoir enters cylinder 1. under the action of the compressed air piston 2 is moved upward, presssing spring 4, and stock/rod 3 is produced the start of switch.

Cutoff/disconnection is conducted by the usual disconnecting electromagnet, acting on the free release of drive.

Fundamental advantages of pneumatic drives: simplicity of construction/design, large reliability of operation, small cost/value, simplicity of operation, small sizes/dimensions, small required electrical power. Their deficiency/lack is the need for

having installation of the compressed air.

With Soviet industry are manufactured the pneumatic drives of the type PV-30, intended for control of six-tank oil switches with a small space of oil of types of MG-10 and MG-20.

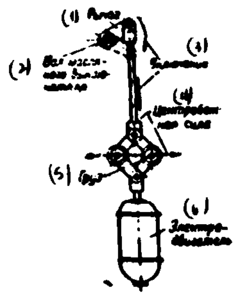

Fig. 18-12.

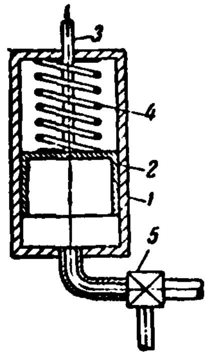

Fig 18-13.

Fig. 18-12. Diagram of centrifugal drive.

Key: (1). Lever. (2). Shaft of oil switch. (3). Start. (4). Centrifugal force. (5). Load. (6). Electric motor.

Fig. 18-13. Diagram of pneumatic drive.

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Drives are calculated for working air pressure 20 Atm(gage) and are equipped with the electromagnets of start and cutoff/disconnection to voltages 110/220V (with switching).

In air high-voltage switches the pneumatic drive is the integral part of the switch itself.

Chapter Nineteen.

Current Transformers.

19-1. General information.

Current transformers apply in the installations of alternating current of all voltages for the feed of the consecutive coils of measuring meters and relay protection. The primary winding of current transformer (Fig. 19-1) is connected consecutively/serially, and to secondary winding also consecutively/serially connect the coils of instruments and relay.

A number of turns w_2 of secondary winding of current transformer several times is more than a number of turns w_1 of its primary winding; therefore secondary current I_2 is less than the primary current I_1.

The transformation of current by current transformer characterizes its nominal transformation ratio (designated on its panel):

$$k_{\text{ном}} = \frac{I_{1\,\text{ном}}}{I_{2\,\text{ном}}} \approx \frac{w_2}{w_1}, \qquad (19\text{-}1)$$

where $I_{1\,ном}$ and $I_{2\,ном}$ — nominal primary and secondary currents of current transformer.

Current transformers are manufactured with such transformation ratios with which their nominal secondary current is usually equal to 5 or 1 A. Respectively for the same current are designed the consecutive coils of instruments and the relays, connected up current transformers.

Between primary and secondary windings of current transformer there is no electric coupling (Fig. 19-1); therefore they greatly reliably insulate instruments and relay from the voltage of installation, which, in the first place, makes it possible to apply instruments and relay with insulation to voltage of up to 1000V (secondary voltage of current transformers in normal mode does not usually exceed several ten volts) and, in the second place, provides the safety of their maintenance/servicing.

So that with the breakdown of insulation between primary and secondary windings the secondary circuit of current transformer would not prove to be with respect to the earth/ground under the voltage of primary circuit, which can be dangerously for personnel and can lead

to breakdown to the earth of the insulation of any element/cell of secondary circuit, in installations by voltage of 500V and above compulsorily are grounded secondary windings of current transformers (Fig. 19-1).

In the presence of the grounding indicated and with the breakdown of insulation between shunt windings relative to earth/ground U_3 of the secondary circuit of current transformer proves to be equal to a voltage drop across the resistor/resistance of the grounding device/equipment r_3 with the course through it of the current of single-phase closing/shorting to the earth I_3 of the network of the primary voltage (see Chapter 5), i.e., $U_3=I_3r_3$ (for greater detail, see Vol. 2, chapter 21).

Thus, because of the use/application of current transformers in the installations of all voltages and at any values of operating currents prove to be possible to apply instruments and relay with insulation to voltage of up to 1000V and with the windings, calculated for small operating currents - 5 or 1 A, which considerably simplifies their construction/design. Such instruments are cheap, reliable and they can possess the high accuracy of measurement. In this case one should consider that in installations voltage above 500 V and in installations with large operating currents the start of instruments and relay without current transformers is generally very difficultly or even it is impossible.

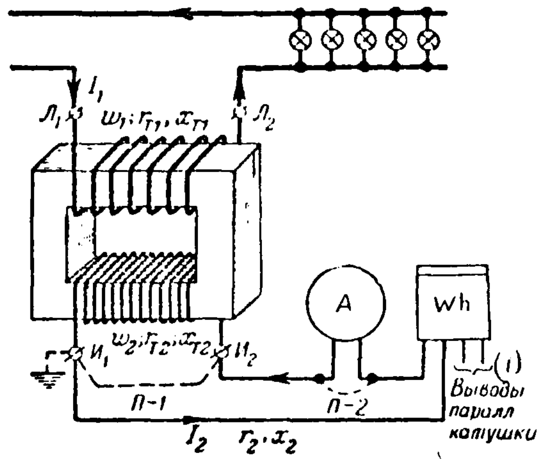

Fig. 19-1. Schematic of the device/equipment of current transformer.

Key: (1). Conclusion/output of parallel coil.

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Upon start through current transformers devices and relay can be placed in considerable distance from that circuit, in which is conducted the measurement. For the connection of current transformers with instruments and relay are utilized the wires and the cables of the comparatively small sections: from 1.5-2.5 to 6-10 мм^2.

For convenience in the operation measuring meter, to show or to consider the real value of the primary circuit: ammeter - current

dial face is calibrated in accordance with the transformation ratio of that current transformer, with which this instrument will be used, which is indicated on dial face.

The special feature/peculiarity of current transformer is the fact that the strength of current I_1 in its primary winding does not depend on the load of secondary circuit (from the value of secondary current I_2), but it is determined exclusively by the current of the load of primary circuit, into which it is connected in series (in power transformers with a change in secondary current varies also primary current). Therefore also the magnetic flux of primary winding, created by the current of the load of primary circuit, does not change with a change of the current in secondary circuit.

By load of current transformer in ohms is understood impedance of its entire external s .dary circuit z_2, equal to the sum of the resistors/resistances of all series-connected coils of measuring meters and relay $(\Sigma r_{приб}; \Sigma x_{приб})$, and also jumpers $(r_{пров})$ and contacts $(r_{конт})$. If we do not consider insignificant in value the inductive reactance of wires from current transformer to instruments, then it is possible to write:

$$z_2 = \sqrt{(\Sigma r_{приб} + r_{пров} + r_{конт})^2 + (\Sigma x_{приб})^2}. \quad (19\text{-}2)$$

Burden of current transformer in the volt-amperes:

$$S_2 = I_2^2 z_2. \quad (19\text{-}3)$$

From formula (19-3) it is evident that with nominal secondary current of current transformer, equal to 1A, the power losses in jumpers and contacts are 25 times less in comparison with losses with the minimum secondary current of 5 A. This is allowed at assigned nominal load $z_{2\,ном}$ or nominal power $S_{2\,ном}$ of current transformer to considerably decrease the section of jumpers from current transformer to measuring meters, which has especially substantially a value in the installations of very high voltages and large power, where as a result of the large overall sizes of distributors the length of jumpers can reach several hundred meters. Furthermore, with secondary current 1A more easily it is cheaper very current transformers as well as connected up them instruments and relay.

Soviet plants manufacture with nominal secondary current 1 A some current transformers for external installations by voltage 110 kV and it is above, and also current transformers, incorporated into power transformers by voltage are 110 kV and are above.

The value of burden z_2 of current transformer is usually small; therefore it operates in mode/conditions, close to the mode/conditions of short circuit. In this an essential difference in

current transformers from power transformers.

Fig. 19-2 gives vector diagram of current transformer, from which it is evident that during normal mode resulting magnetizing force (NS) $\dot{\theta}_0=\dot{\theta}_1+\dot{\theta}_2$ is small.

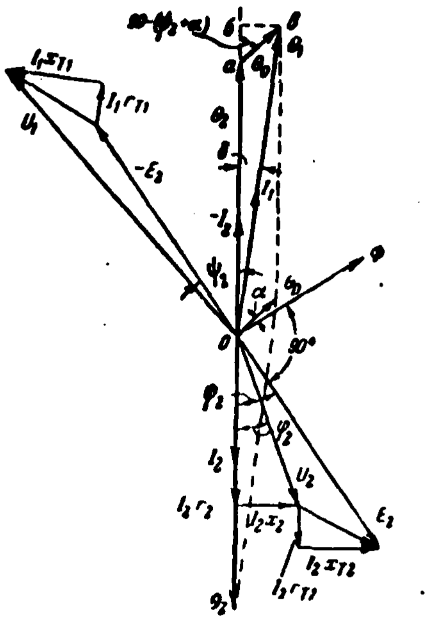

Fig. 19-2. Vector diagram of current transformer.

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Therefore they are small resulting magnetic flux Φ in core and emf. E_2 secondary winding.

For the purpose the decreases of overall sizes, weight and cost/value of current transformers the section of their cores determine, on the basis of the low value of the resulting magnetic flux of the normal mode of work (with calculated magnetic induction B in steel, the section of core $s = \frac{\Phi}{B}$).

If we in located in work current transformer(with the course of current in primary circuit) disconnect secondary circuit ($z_2=\infty$), then $I_2=0$ and $\theta_2=I_2w_2=0$. Since in this case primary current I_1 and NS of primary winding $\theta_1=I_1w_1$ they remain constant/invariable, then the resultant NS θ_0 becomes equal to the NS of the primary winding θ_1, i.e., grows/rises many times. Accordingly increase magnetic flux Φ (its growth it is limited to the saturation of core) and induction in steel of core.

A considerable increase in the induction leads to the strong heating of core as a result of the increased losses in steel, as a result of which usually are overheating the insulation of windings and damage of current transformer. Furthermore, in secondary winding is induced considerable emf whose value is determined not only by an increase in the magnetic flux, but also by the fact that as a result of saturating the core the magnetic flux has no longer sinusoidal, but trapezoidal form (Fig. 19-3). Since the value of secondary emf is proportional to rate of change in magnetic flux $\left(\frac{d\Phi}{dt}\right)$, then at the moments of a rapid change of the flow in secondary winding of current transformer is induced very large emf (e_2 in Fig. 19-3) whose peaks can reach several thousand and even tens of thousands of volts (they increase with an increase in the transformation ratio of current

transformer, i.e., its nominal primary current). The corresponding ceiling voltages appear at the terminals/grippers of extended secondary winding of current transformer, which is dangerous for the service personnel and for the insulation of instruments, relay and jumpers and cables.

From the aforesaid it follows that in operation it is not possible to disrupt the secondary circuit of located in work current transformer. If necessary to disconnect measuring meter in working current transformer should be preliminarily short circuited his secondary winding or disconnected instrument (broken cross connections P-1 or P-2 in the diagram of Fig. 19-1) and after this only disconnected the instrument.

Current transformers introduce as a result of the measurement of two errors: error in the strength of current (in transformation ratio) ΔI and the angular error δ.

If current transformer worked without error in the current strength, then, accordingly formula (19-1), value of secondary current, led to primary circuit, i.e., $I_2 k_{ном}$, would be equal to primary current I_1. In actuality indicated value are not equal and their algebraic equality

$$I_2 k_{ном} - I_1 = \pm \Delta I \qquad (19\text{-}4)$$

and it is an error in current transformer in the strength of measured current. Plus signs and minus before ΔI show that given secondary current can be more or less than I_1.

This error can be expressed in percentages of the measured current I_1:

$$\Delta I\% = \frac{I_2 k_{\text{ном}} - I_1}{I_1} 100. \qquad (19\text{-}5)$$

Since

$$k_{\text{ном}} \approx \frac{w_1}{w_2},$$

that

$$\Delta I\% = \frac{I_2 w_2 - I_1 w_1}{I_1 w_1} 100 = \frac{\theta_2 - \theta_1}{\theta_1} 100.$$

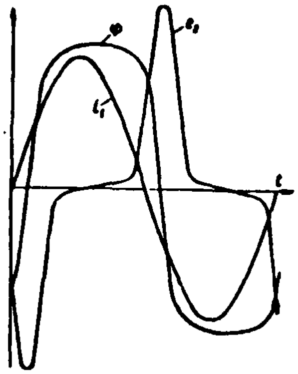

Fig. 1-3. Curves of primary current i_1, magnetic flux Φ and emf e_2 of secondary winding of current transformer with the extended secondary circuit.

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From vector diagram on Fig. 19-2 we find (accepting cut $0\delta \approx \theta_1$):

$$\theta_2 - \theta_1 \approx - \theta_0 \sin(\psi_2 + \alpha).$$

Angle α very ~~mal~~ small, therefore can be written:

$$\Delta I\% \approx - \frac{\theta_0 \sin \psi_2}{\theta_1} 100. \qquad (19\text{-}6)$$

An angular error in current transformer is called angle δ between the vector of primary current I_1 and the turned on 180° vector of secondary current $-I_2$ (or, which is the same thing, the angle between vectors θ_1 and $-\theta_2$, see Fig. 19-2). From vector diagram we find:

$$\operatorname{tg} \delta \approx \frac{\theta_0 \cos \psi_2}{\theta_1}.$$

As a result of the very low value of angle δ it is possible to accept tgδ≈δ (in radians), then

$$\delta \approx \frac{\theta_0 \cos\psi_2}{\theta_1}. \qquad (19\text{-}7)$$

From vector diagram in Fig. 19-2 and formulas (19-6) and (19-7) it is evident that both errors in current transformer depend on that resulting NS θ_0, with increase in which they increase.

For decrease in NS θ_0 is necessary the decrease of reluctance $r_M = \frac{l}{\mu s}$ — the transformer core of current, which can be achieved/reached: by a decrease of length l of magnetic circuit, by an increase in the cross-sectional area s of core and by the use/application of transformer steel with high magnetic permeability μ. Vital importance has decrease of air gaps on the path of magnetic flux.

The transformer cores of current manufacture from thin steel tapes or plates, isolated/insulated from each other by the natural oxide film, which is retained on the sheets of steel after its rolling and annealing at metallurgical plant [19-1].

With an increase in the cross-sectional area of core both errors in current transformer decrease, but is reached this due to an increase in its overall sizes, weight and cost/value.

At present for producing the transformer cores of current are used extensively steels with the high magnetic permeability: cold-rolled silicon steel ($\mu_{макс}$ to 26,000) and glory from iron with nickel, so-called Permalloy ($\mu_{макс}$ to 70,000). For a comparison let us point out that hot-rolled silicon steel possesses $\mu_{макс}$ to 7500-10,000. Steel with high magnetic permeability allows with constant/invariable overall sizes and weight to obtain current transformers with smaller errors or with the same errors substantial to decrease the overall sizes and the weight of current transformers [L. 9-1].

In some types of current transformers an increase of the accuracy of measurement in the range of primary currents to 100-120o/o of nominal is achieved with the aid of different artificial methods of the compensation errors. The essence of these methods of compensation consists in an improvement in the magnetic properties of the material of core via magnetic biasing by one or another method, which depends on the method of compensation. Core is magnetized so that its working induction could be led to the value, corresponding to the region of the greatest magnetic permeability of the material of core. Therefore decrease the NS θ_0 and errors in

current transformer (for greater detail, see 9-1 and 19-1].

From formulas (19-6) and (19-7) it is evident that with an increase in relative value of inductive reactance of secondary circuit, i.e., with increase ψ_2, the error in current increases ($\sin\psi_2$ it increases), and the angular error decreases ($\cos\psi_2$ it decreases).

With an increase in the primary MS θ_1 both errors in current transformers decrease. At specific value $I_{1ном}$ an increase θ_1 is achieved by an increase in the number of turns of primary winding w_1. simultaneously for obtaining assigned magnitude $I_{2ном}$ must be (accordingly formula 19-1) is respectively increased a number of turns of secondary winding w_2. As a result this weight, overall sizes and cost/value of current transformer they substantially increase.

From the aforesaid it also follows that current transformers to small primary currents can be made only with sufficiently large number of the turns of primary winding, otherwise of their error they will be considerable even with small burden.

Magnitudes of error of current transformers to a considerable degree depend on their use in operation.

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With an increase in the primary current to 100-120o/o $I_{1ном}$ of error in current transformer they decrease as a result of an increase θ_1 (see Table 19-1). With further increase in the primary current of error they increase as a result of the saturation of the magnetic system of current transformer. Therefore current transformers, established/installed with the considerable excess of their nominal primary current with respect to the operating current of circuit, work with the increased errors.

An increase in the load of the secondary circuit z_2 with constant/invariable primary current (constant quantity θ_1) leads to certain decrease of I_2 and θ_2, and consequently, to an increase θ_0 (see vector diagram), as a result of which both errors in current transformer increase. Therefore the connected to current transformer measuring meters give sufficiently precise readings only at some specific values of z_2 or S_2.

An error in current transformer in the current strength introduces the error into readings of all measuring meters, and the angular error has a value only for instruments and wattmeter type relay, for example wattmeters, counters, etc. Is explained this by the fact that angular error of current transformer changes the angle

between vectors of current and voltage, i.e., distorts the value of the factor of the power of the circuit [instead of cosϕ it is obtained by cos (ϕ+-δ)], that also gives supplementary fault of measurement of energy, power or cos ϕ.

Current transformers are subdivided into the classes of precision which are characterized by the greatest permissible errors, indicated in Table 19-1. The digital designations of the class of precision correspond to the smallest percentage errors in current.

Current transformer can work in the different classes of precision depending on the value of its secondary load z_2 or S_2, moreover to each class of precision corresponds specific nominal burden $z_{2\,ном}$ (ohm) or power $S_{2\,ном}=I^2_{2\,ном}z_{2\,ном}$ (VA) which are given in catalogs or plant informational materials (Table P-17).

If, for example, for certain current transformer it is shown that its nominal power in the class of precision 0.5 is 30 VA, and in the class of precision 1 it is 60 VA, then this means that with burden to 30 VA inclusively of current transformer it works in the class of precision 0.5, and with load from 30 to 60 VA inclusively - in the class of precision 1. With the load of more than 60 VA current transformer works already in the class of precision 3.

They characterize current transformer by that highest class of precision in which it can work (it is indicated in its certified/rating table).

Table 19-1. Greatest permissible errors in current transformers (GOST 7746-55).

(1) Класс точности	(2) Ток в первичной обмотке, % номинального	(3) Наибольшие погрешности: (4) в токе, %	(3) Наибольшие погрешности: (5) угловая, мин	(6) Примечание
0,2	(7) От 120 (8) до 100 20 10	±0,20 ±0,35 ±0,50	±10 ±15 ±20	(9) Для вторичной нагрузки в пределах от 25 до 100% номинального значения и при вторичном коэффициенте мощности $\cos\varphi_2 = 0{,}8$. При этом минимальное значение вторичной нагрузки должно быть не ниже 0,15 *ом* для трансформаторов тока с номинальным вторичным током 5 *а* и 1,5 *ом* для трансформаторов тока с номинальным вторичным током 1 *а*.
0,5	(7) От 120 (8) до 100 20 10	±0,50 ±0,75 ±1,0	±40 ±50 ±60	
1	(7) От 120 (8) до 100 20 10	±1,0 ±1,5 ±2,0	±80 ±100 ±120	
3	(7) От 120 (8) до 50	±3	(10) Не нормируется	
10	(7) От 120 (8) до 50	±10		

Key: (1). Class of precision. (2). Current in primary winding, o/o nominal. (3). Greatest errors. (4). in current. (5). angular, min. (6). Note. (7). From. (8). to. (9). For burden in limits from 25 to 100o/o of nominal value also with secondary factor of power cos ϕ_2=0.8. In this case the minimum value of burden must be not below 0.15 ohms for current transformers with nominal secondary current 5 A and 1.5 ohms for current transformers with nominal secondary current 1 A. (10). It is not normalized.

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Current transformers of the class of precision 0.2 are applied only for precise laboratory measurements. For the start of attendant electric measuring instruments apply current transformers of the classes of precision not lower than 3 [1. 3-6, §I-6-3 and 19-2, III-4-4].

Calculated counters should be connected up current transformers, which work in the class of precision 0.5. the calculated counters include all counters, on which the consumers are designed for electric power with the power-supply organization, and also counters, adjusted in the circuits of generators, power transformers, lines, which feed their own needs also of the waste/exiting from collecting mains of power plants and substations.

The monitor counters, which use for the technical account to electric power within power plants, substations, enterprises, etc., can be connected up current transformers of the class of precision 1 [3-6, §I-5-17].

Attendant wattmeters, reactive/jet ampere-voltmeters, phasemeters and ammeters can be connected up current transformers of the classes of precision 1 and 3.

Calculated counter and another electric measuring instruments of

one circuit can be connected together to general/common/total current transformer which in this case must work in the class of precision 0.5. It is possible also to connect up one current transformer measuring meters and relay of the protection of one circuit, if with is retained the work of current transformer in the class of precision, necessary for the connected instruments, and if this does not lead to a change in the characteristics of relaying [3-6, §I-5-18].

In the devices/equipment of relaying must be provided the correct action of relay with the onset in the current circuit of overloading or short circuit. Therefore current transformers, used for relayings, must possess the necessary accuracy not with the currents of normal mode, but with the currents, which considerably exceed their nominal primary current. On the basis of operating experience it is established/installed, that for providing the clear and reliable work of relayings of an error in current transformers with the currents of emergency mode, as a rule, they must not exceed: in current minus 10o/o and in angle of 7° [19-3].

for the majority of relayings these conditions are provided during the use/application of current transformers of the classes of precision 1 and 3. In some current transformers with the cast insulation (see §19-3) of core for relaying are designated by letter

R (table P-17).

For differential relayings are applied special current transformers of the type D (see Vol. 2, chapter 13).

The intended for diagrams compoundings of the excitation of the synchronous machines (see §22-5) current transformers of the type K have nominal secondary current 10 A.

19-2. Diagrams of connections of current transformers.

Here we will be restricted to the examination of the diagrams of connections of current transformers, most commonly used for start electric measuring instruments (Fig. 19-4).

Diagram a apply for measuring the current in one phase in the three-wire installations of three-phase current with small nonuniformity the loads of phases.

Connection into star (diagram b) apply for the inclusion of instruments in the three-wire installations of three-phase current with considerable nonuniformity the loads of phases, and also in four-wire installations 380/220 and 220/127V.

Connection into incomplete star (diagram c) uses extensively for the inclusion of measuring meters in three-wire installations with the uniform and unbalanced loads of phases. The current, flowing through the ammeter in common wire, is equal to vector sum of currents in phases A and C, i.e., it is equal to the current of phase B. For the installations indicated is always correct the condition:

$$\dot{I}_A+\dot{I}_B+\dot{I}_C=0 \text{ (1) откуда } \dot{I}_B=-(\dot{I}_A+\dot{I}_C).$$

Key: (1). whence.

The ends/leads of the primary winding of the transformer of current have plant designation by letters L_1 and L_2, and secondary windings - by letters I_1 and I_2. With the course of primary current from L_1 and L_2 secondary current over the connected to current transformer instruments and relay flows/occurs/lasts from I_1 and I_2 (Fig. 10-4a).

19-3. Constructions/designs of current transformers.

Soviet plant manufacture current transformers to all voltages to 500 kV inclusively (Table P-17).

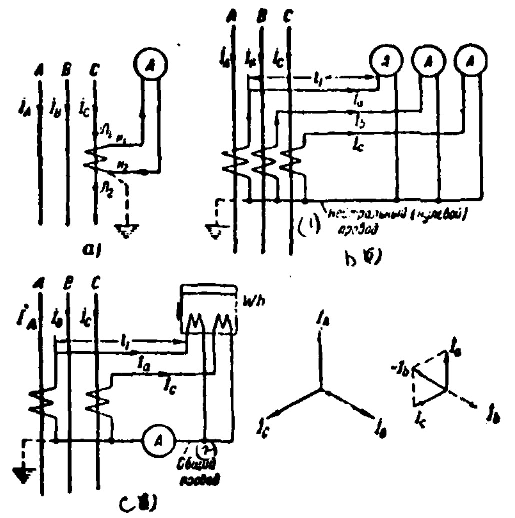

Fig. 19-4. Diagrams of connections of current transformers.

Key: (1). Neutral (zero) wire. (2). Common wire.

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By the construction/design of primary winding distinguish current transformers single-turn (rod) and multiturn (loop, reel).

The primary windings of single-turns transformer (Fig. 19-5a) perform from the round cruxes of continuous or tubular section or from the packet of busbars. Main disadvantage in these current transformers is their low accuracy with small measured currents as a

result of the fact that with a small primary current value of the NS of the primary winding ($\theta_1=I_1w_1=I_1\cdot1=I_1$) is insufficient for maintaining the necessary magnetic flux and the power of secondary winding is insignificant. However, an excessive increase in the section of core is inexpedient. Therefore single-turns transformer manufacture to nominal primary currents from 150-200 A also more. To currents 600-1000 A also more are manufactured only single-turns transformer (Table P-17).

To the advantages of single-turns transformer in comparison with multiturn ones can be attributed their simpler construction/design less cost/value, smaller overall sizes and large stability with short-circuit currents. Internal electrodynamic forces in them are small, and thermal resistance is achieved easily - by a change in the section of current-carrying rod 1.

The primary windings of multiturn current transformers (Fig. 19-5b) perform from several turns, which encompass core with superimposed to it secondary winding. In this case at a small primary current the necessary value of NS of primary winding $\theta_1=I_1w_1$ is reached by an increase in the number of turns w_1 of the primary winding of current transformer(for retaining/preserving/maintaining the necessary transformation ratio current transformer respectively increases a number of turns w_2 of its secondary winding). Therefore

it proves to be possible to perform multiturn current transformers of the high classes of precision with the low values of nominal primary currents. Soviet plants manufacture multiturn current transformers to nominal primary currents from 5 to 600 A (Table P-17).

Main disadvantages in multiturn current transformers escape/ensue of the advantages presented above of single-turns transformer. A deficiency/lack in the multiturn constructions/designs is also the fact that their primary windings undergo considerable overvoltages between turns with the incidence/drop on the transformer of the wave of overvoltage or with the course of large short-circuit currents.

By the number of cores are distinguished current transformers with one and several cores. Fig. 19-5c gives the schematic of multiturn current transformer with two cores each of which has their independent winding. primary winding for both cores general/common/total; therefore is obtained as if duplication of current transformer with virtually constant/invariable overall sizes and small change in the cost/value.

Core coils are completely not depended from each other: a change in the load of one secondary winding does not manifest itself the value of primary current, and consequently, it does not affect

magnitude of error in the second core.

Cores can have the different and identical classes of precision and be utilized for the separate start of measuring meters, relayings and relay of automation.

some current transformers by voltage 35 kV and higher are manufactured with three and four cores, which gives essential savings.

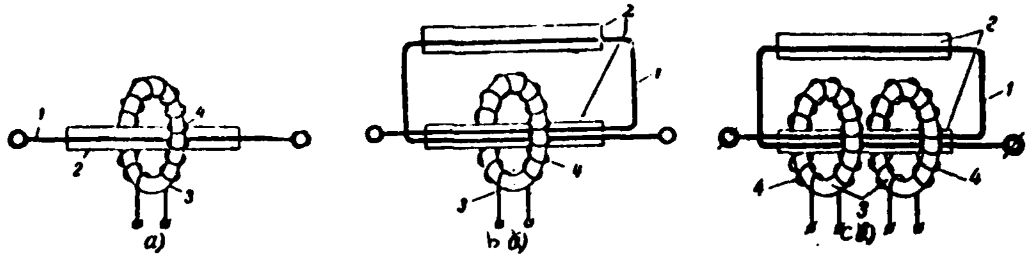

Fig. 19-5. Schematic diagrams of the device/equipment of current transformers. a) single-turn; b) multiturn with one core; c) multiturn with two cores. 1 - primary winding; 2 - insulation; 3 - core; 4 - secondary winding.

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Using mounting method current transformers passage (Fig. 19-6, 19-7, etc.) and supporting/reference (Fig. 19-10, 19-11, etc.). In special group it is possible to isolate built-in current transformers, adjusted within other apparatuses and machines.

By kind the installations distinguish current transformers for internal and external installation.

Let us become acquainted with the primary constructions of current transformers of Soviet plants.

Passage of transformers of current are intended only for closed distributive units and can be used for installation in the openings of walls and overlaps instead of wall entrance insulators, which substantially decreases the overall sizes and the cost/value of distributors. If necessary them are installed also in the metal constructions of distributors.

Passage current transformers are most widely used current transformers in the closed distributors by voltage to 20 kV inclusively.

Passage current transformers can have one or two cores to secondary windings of the identical or different classes of precision.

For installations with large short-circuit currents are manufactured passage current transformers of intensive type, which possess larger stability during short circuits. Into a designation of the type of such current transformers enters the letter U.

Passage multiturn current transformers with porcelain insulation (Fig. 19-6) of the type TPFM (T - current transformer, P - passage, F - with porcelain insulation, M - modernized; previously they were released type TPF) are manufactured to nominal voltage 10 kV and

nominal primary currents 5 -400 A.

The primary winding of this current transformer passes within porcelain insulators 1, attached in collar 2 and from both ends/leads of those fastened additionally as cast iron end cases 3. turn-to-turn insulation of primary winding is designed for the voltage, equal to a voltage drop in the turn of winding with flow on it of the maximum permissible short-term current.

The ends/leads of primary winding are connected to contact plates 4, employees for connection to current transformer of the busbars of distributing device/equipment.

The core, assembled from L-shaped steel plates, encompasses porcelain insulator 1, within which are located the conductors of primary winding. To core is put on the coil of secondary winding whose ends/leads are brought out to terminals/grippers 5. Depicted in Fig. 19-6 current transformer has two cores, the ends/leads of winding of which are brought out to terminals/grippers 5 and 5'. Cores with secondary windings with enclosed casing 6.

In all passage current transformers with porcelain insulation the primary winding of high voltage is reliably isolated/insulated by porcelain from the grounded collar and from core and secondary

winding. The external surface of porcelain insulators in part, which is located under cores, is covered with the layer of the carrying out graphite paint and is connected electrically with the grounded armature. In multiturn current transformers the same paint covered also and internal cavity of both insulators, connected electrically with primary winding. All this is necessary for warning/preventing the ionization of the air layer between metallic parts and insulator, adversely affecting the organic insulation of windings.

Passage single-turn (rod) current transformers. Are most common passage single-turns transformer with porcelain insulation (Fig. 19-7) of the type TPOF (O - single-turn), manufactured to nominal voltages 10 and 20 kV and rated currents 600 and 1500 A.

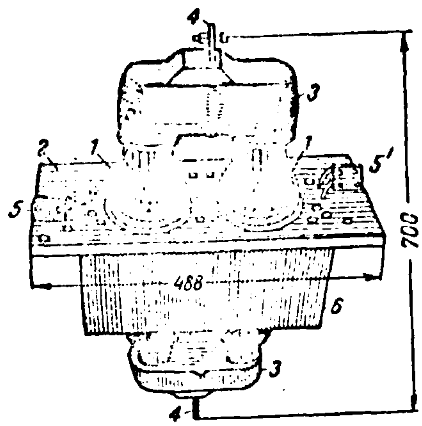

Fig. 19-6. Passage multiturn current transformer with porcelain insulation of the type TPRM-10 on 10 kV, 100 A, with two cores.

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In these current transformers the role of primary winding performs current-carrying rod 1, which passes within porcelain insulator 2, attached in collar 3, which uses for the attachment of current transformer.

Core has circular form and is made from the tightly wound by spiral tapes of transformer steel. to core is wound secondary winding (as in Fig. 19-5a). Core together with secondary winding is put on to the middle part of porcelain insulator 2 and with enclosed casing 4. The ends/leads of secondary windings are brought out to

terminals/grippers 5 and 5'. Nuts 6 serve for the attachment of the busbars of primary circuit.

In recent years all more widely begin to manufacture current transformers with insulation from the cast synthetic resin. The synthetic resins used with filling are very movable and after polymerization harden with the formation of monolithic mass without bubbles. This insulation possesses high and permanent electrical properties. Soviet plants apply compound on the base of epoxy resin.

Fig. 19-8 shows passage single-turn transformer with the cast resinous insulation of the type TPOL-10, manufactured to voltage 10 kV and rated currents 600-1500 A. current-carrying rod 1 (primary winding) with the put on to it two cores with secondary windings they are flooded by compound 2, which not only provides reliable insulation, but also shields the windings of current transformer from mechanical damages. Collar 3 serves for attachment of current transformer.

From the comparison of the overall dimensions of single-turns transformer with the porcelain and cast resinous insulation (Fig. 19-7 and 19-8) it is evident that the sizes/dimensions of the second are considerably less.

Passage busbar/tire current transformers with porcelain insulation apply in the installations of high voltage with very large operating currents 2 kA even more. From passage single-turn (rod) current transformers (Fig. 19-7) they are characterized by the fact that they are supplied by plants without the current-carrying rods (primary windings), instead of which are utilized the busbars or the packets of the busbars of the distributor which during mounting pass through the internal by the cavity of porcelain housing (insulator) of 6 current transformers (Fig. 19-9). The diameter of porcelain housing, and also the sizes/dimensions of openings/apertures 3 in its caps/hoods and of pressure pads 2, which use for the attachment of busbars, are calculated for the passage of busbar or packet of busbars to operating currents 2 kA and more.

Cores and secondary windings of these current transformers, made just as in single-turns transformer on Fig. 19-7, with enclosed casing 5. The ends/leads of secondary windings are brought out to terminals/grippers 1 and 1', established/installed on collar 4, which uses for the attachment of current transformer.

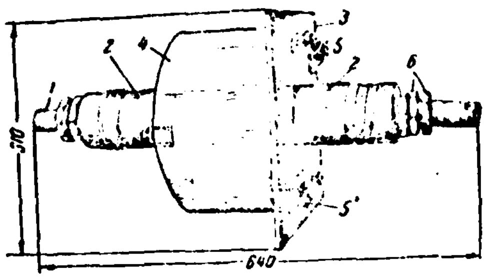

Fig. 19-7.

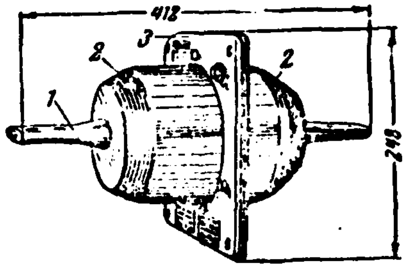

Fig. 19-8.

Fig. 19-7. Passage single-turn transformer with porcelain insulation of type TPOF-10 on 10 kV, 1000 A, with two cores.

Fig. 19-8. Passage single-turn transformer with cast resinous insulation of type TPOL-10 on 10 kV, 1000 A, with two cores.

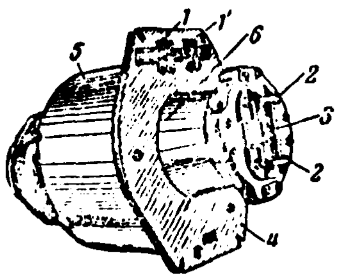

Fig. 19-9. Passage busbar/tire current transformer with porcelain insulation of type TPShF-10 on 10 kV, 3 kA, with two cores.

1 and 1' - outputs of secondary windings; 2 - pressure pads for the

busbars; 3 - opening/aperture for the introduction/input of the busbars; 4 - collar; 5 - jacket; 6 - porcelain insulator.

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Soviet plant manufacture passage busbar/tire current transformers to nominal voltages 10 and 20 kV and primary currents 2000-6000 A type TPShFA (Sh - busbar/tire, A - conventional designations of the mechanical attachment of armature on the porcelain; in current transformers of the type TPShF armature it was secured with the aid of the cementing composition).

The collars of passage current transformers to 600 A inclusively are performed from gray cast iron, and to high currents - from non-magnetic cast iron. The jackets of current transformers to 1000 A also more have section/cut into which is inserted brass plank for decreasing heating jacket by eddy currents, also, as a result of hysteresis.

Supporting/reference current transformers are intended for installation during the constructions/designs of distributors and can be made for internal and external installations.

Supporting/reference current transformers with shaped porcelain

insulators and loop primary winding (multiturn) of the type TP are manufactured for internal installations to nominal voltage 10 kV and nominal primary currents 15-600 A.

Primary winding 1 (Fig. 19-10), made in the form of multiturn loop from flexible insulated wire, is placed within shaped hollow porcelain insulator 4. Secondary winding by 2 is placed in the window of porcelain insulator on 3 armor types cores, collected from thin steel L-shaped plates. Core encompasses both parts of the loop of primary winding. Current transformer can have one or two cores, arranged/located one above another, kA this evidently on Fig. 19-10.

Insulator is attached in cast iron base 6, which serves for the attachment of current transformer during the construction/design of distributor. Cores and secondary windings are shielded by jacket 5.

With the purpose of an increase in the electrodynamic stability of current transformer and improvement in its thermal characteristics the internal cavity of shaped insulator 4 is filled with pure/clean quartz sand 7.

The presence of sand does not make it possible to install these current transformers in the vertical walls (it is inclined) and on the ceiling; should be installed them only on the horizontal pads.

In comparison with passage multiturn ones current transformers of the type TP have substantially less overall sizes and weight of copper, they are more reliable. Are applied them in various kinds the small/miniature closed distributors.

Reel current transformers are supporting/reference multiturn current transformers with dry insulation and without protective housings. They are suitable for internal installation.

For Installations by voltage of up to 500 V inclusively Soviet plants manufacture reel current transformers of several types: TKM and O-49U to primary currents 5-750 A and TTM - to 50-200 A [9-2].

To voltage 500 V Soviet plants manufacture also reel current transformers with the cast resinous insulation of the type TKL-0.5 to nominal primary currents 5-300 A with one core of the class of precision 0.5.

To voltage 10 kV and rated currents 5-400 A Soviet plants manufacture current transformers with the cast resinous insulation of types TKL-10 (Fig. 19-11) and TPL-10 (Fig. 19-12) with one and two cores. Current transformers indicated in essence are characterized by

the location of the outputs or the primary winding: in the first the conclusions are arranged/located as in usual reel current transformers (above series/row), and in the second - as in passage current transformers (see conclusion/output L_1 and L_2 in Fig. 19-11 and 19-12).

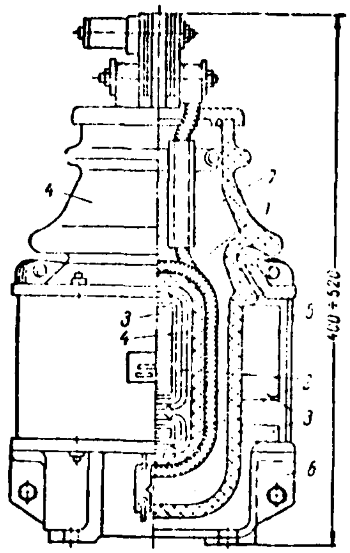

Fig. 19-10. Supporting/reference porcelain shaped current transformer of the type TF on 10 kV. 1 - primary winding; 2 - two secondary windings; 3 - armor type two cores; 4 - shaped porcelain insulator; 5 - jacket; 6 - cast iron base; 7 - quartz sand.

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Before the Soviet plants has been set the problem within the next few years mastering the production of current transformers with the cast insulation to all voltages to 35 kV inclusively, and subsequently and to voltage 110 kV.

Supporting/reference busbar/tire current transformers are related to the group of single-turn ones. They consist of the core with secondary winding, which is slipped over the busbar of distributor, the performing role of primary winding.

For installations by voltage to 500 V inclusively Soviet plants manufacture supporting/reference busbar/tire current transformers of the type TTM to primary currents 400-1000 A also type TNSh to currents 750-25,000 A [9-2], and also with the cast resinous insulation of the type TShL-0.5 to primary currents 400, 600 and 800 A.

To high voltages the very packaged designs of busbar/tire current transformers are obtained during the use/application of the cast resinous insulation. Fig. 19-13 shows similar Soviet current transformer of the type TShL20-10,000-D/0.5 to voltage 20 kV, primary current 10,000 A, secondary current 5 A, with two cores, a class of precision 0.5 and type D. In section/cut are visible cores 1 and 2 with secondary windings and cast epoxy insulation 3.

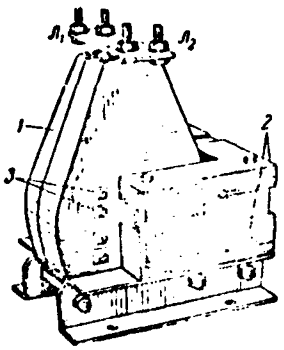

Fig. 19-11.

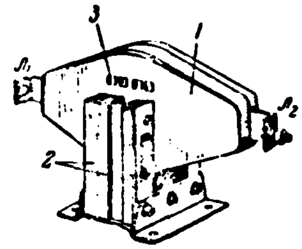

Fig. 19-12.

Fig. 19-11. Reel current transformer with cast resinous insulation of type TKL-10 on 10 kV, 5-400 A, with two cores. 1 - the casting; 2 - cores; 3 - outputs of secondary windings; L_1 and L_2 - terminals/grippers of primary winding.

Fig. 19-12. Reel current transformer with cast resinous insulation of type TPL-10 on 10 kV, 5-400 A, with two cores. 1 - the casting; 2 - cores; 3 - outputs of secondary windings; L_1 and L_2 - terminals/grippers of primary winding.

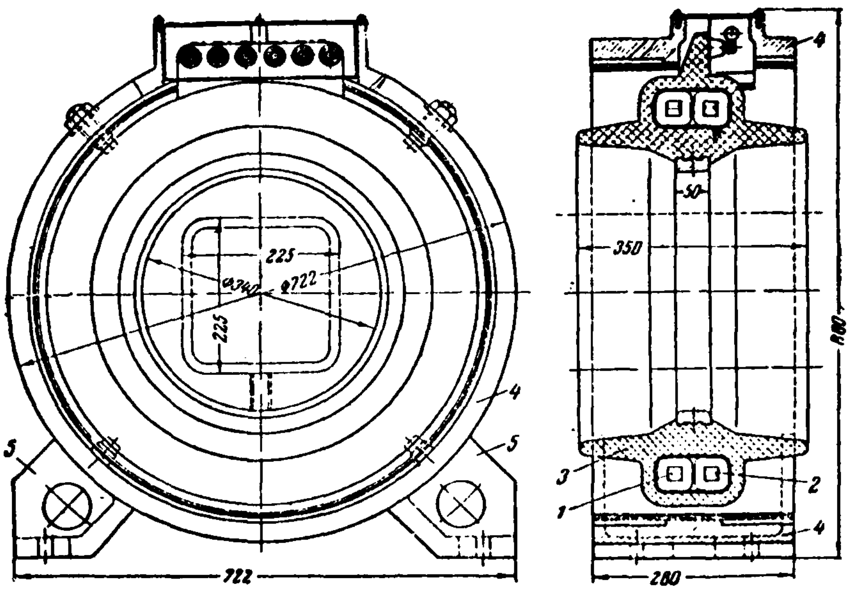

Fig. 19-13. Supporting/reference busbar/tire current transformer with cast insulation of type TShL20-10,000-D/0.5 on 20 kV, 10 kA, with two cores.

Page silumin frame 4 is equipped with feet 5 for the attachment of current transformer which can be set in any position. As primary winding are utilized the busbars (two busbars of box section in high from 200 to 250 mm), which freely pass in the window of current transformer, i.e., not mechanically connected with it.

Supporting/reference porcelain current transformers for external installations. It is earlier in external installations by voltage 35

kV and above were applied current transformers in metal jackets with the passage porcelain insulators which had a number of the essential deficiencies/lacks: the low reliability of operation, large overall sizes and high cost/value. At present these current transformers do not manufacture.

In the newest constructions/designs of current transformers for external installations by voltage 35 kV and above metal casing it is replaced porcelain, in consequence of which was eliminated the need in special wall entrance insulators. The appearance of this current transformer resembles insulator (Fig. 19-14).

Soviet plant manufacture similar current transformers of types TFN and TFNU (N - external installation) to nominal voltages 35-220 kV and to nominal primary currents to 2000 A. In the form of an example Fig. 19-14 gives the section/cut of current transformer of the type TFN-220 to voltage 220 kV. The windings of transformer are placed into porcelain jacket 1, flooded by transformer oil 2. Housing is fastened/strengthened (with hermetic multiplexing) on metallic base 3. To the upper end/face of porcelain housing is fastened/strengthened cast iron oil conservator 4 with cover/cap, equipped with oil indicator tube 5 and safety valve 6.

Core with secondary winding by 7 is fastened/strengthened to

base. Primary winding by 8 encompasses core with secondary winding as two rings, passed through one into another - execution of windings in the form of eight.

Terminals/grippers L_1 and L_2 serve for the connection of primary circuit.

Primary winding is isolated/insulated from those grounded secondary winding and its core to the total voltage of installation with respect to the earth/ground. As insulation are used cable paper and transformer oil (paper-oil insulation). For the purpose of the best use the paper insulation is divided into two parts, one of which is packed to primary winding, and the second - to secondary winding with its core. This separation of insulation (the so-called chain/catenary construction/design of insulation) gives the essential savings of insulation and the decrease of sizes of current transformer.

The even better results are reached at the use/application of cable-condenser/capacitor insulation, analogous insulation of wall entrance insulators to very high voltages. During cable-condenser/capacitor insulation is provided the more even distribution of electric field, in comparison with usual paper-oil insulation how is reached essential gain in the thickness of

insulation. This insulation have current transformers to very high voltages of some foreign firms [19-4].

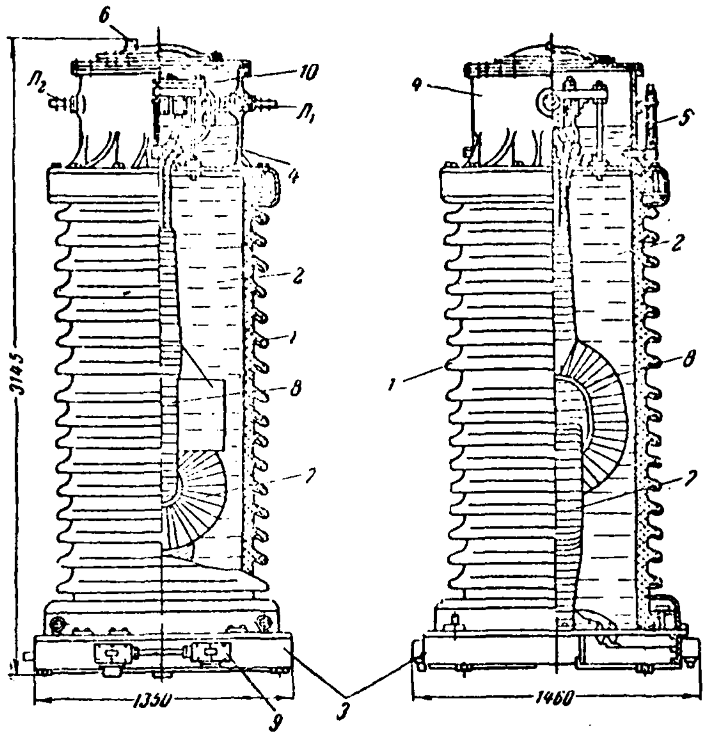

Fig. 19-14. Porcelain supporting/reference current transformer for external installation of the type TFN-220 on 220 kV, 1200 A, with four cores.

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Current transformers of the type TFN at voltages 35 and 110 kV have two or three cores, on 154 kV - three cores and on 220 kV - four cores. The ends/leads of secondary windings are brought out to terminals/grippers, which are located in case 9.

The primary windings of current transformers to voltages 110 and 154 kV consist of two identical sections, connected consecutively/serially or in parallel, that makes it possible one and the same current transformer to utilize at two values of primary current (for example, on 200 and 400 A). The primary windings of current transformers on 220 kV consist of four sections, connecting which in series, in pairs-in parallel or all four sections in parallel it is possible to utilize current transformer at three values of primary current. Switchings of armature coils (after the cutoff/disconnection of current transformer from network/grid) fulfill with the aid of switch 10.

Secondary windings of some current transformers of the type TFN

have branchings, which makes it possible to utilize them to currents less than nominal ones, without switching of the sections of primary winding.

The advantages of supporting/reference porcelain current transformers consist in their small sizes/dimensions, in the considerable power of secondary windings, in high electrodynamic and thermal resistance.

Cascade current transformers. With very high voltages (220 kV it is above) the considerable savings of insulation is reached in current transformers of cascade type. This transformer consists of several those connected to each other of intervening transformers of current (cascades/stages, steps/stages). Fig. 19-15 gives the schematic diagram of two-stage cascade current transformer $\left(k_{\text{ном}}=\frac{I_{1\,\text{ном}}}{I_{2\,\text{ном}}}\right)$.

Each step/stage of two-stage transformer must be isolated/insulated to the half of the voltage of installation with respect to the earth/ground. If moreover, the insulation of each step/stage is fulfilled the chain/catenary construction/design (as in current transformers of the type TFN), then each layer of insulation already must be designed only for 1/4 voltages of installation with respect to the earth/ground, i.e., to voltage, two times it is less than in current transformers of the type TFN.

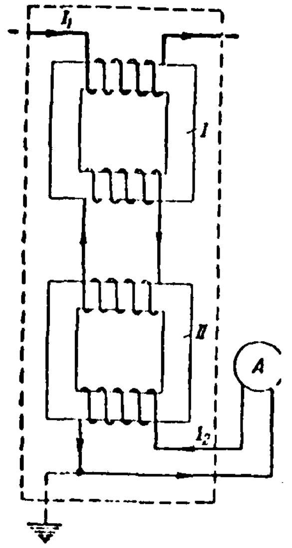

Fig. 19-15. Schematic diagram of cascade current transformer.

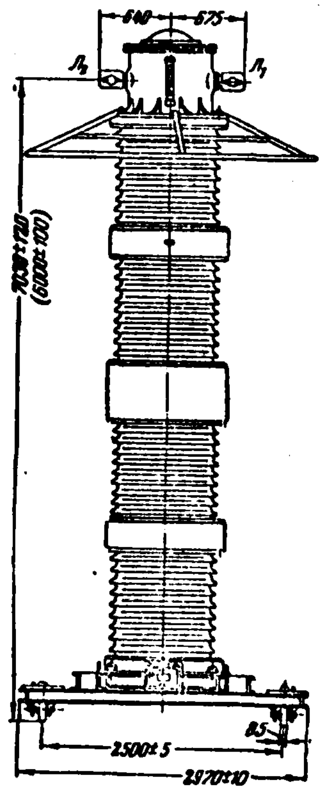

Fig. 19-16. Cascade current transformer of the type TFNK-400 on 400 kV.

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As a result of this are reached the savings of insulation, the decrease of weight and overall sizes of cascade current transformers.

A deficiency/lack in cascade current transformers is high

magnitude of error as a result of the presence of several steps/stages of transformations each of which gives the specific error. For retaining/preserving/maintaining the required class of precision it is necessary to increase the sections of windings and cores, that somewhat decreases the savings during insulation. Therefore they consider that cascade current transformers it is expedient to fulfill not more as to two steps/stages [L. 19-4].

Fig. 19-16 shows the general view of cascade current transformer of the type TFNK-400 to the voltage 400 kV of plant "electrical device". Transformer consists of two steps/stages and has four secondary cores [L. 19-1]. Housing porcelain, split to two parts, which simplifies the transportation of current transformer.

Built-in current transformers, i.e., adjustable within different electrical apparatuses and machines, most use extensively in installations by voltage 35 kV even above. Such current transformers incorporate into oil breakers and power transformers, and also into linear conclusion/output.

Current transformer of this type consists of the annular core with superimposed to it secondary winding, which is slipped over the isolated/insulated current-carrying part of the apparatus, utilized as the primary winding of current transformer. In oil breakers and

power transformers such current transformers fasten under their cover/cap on wall entrance insulators (Fig. 17-8). As primary winding serves the current-carrying rod of insulator. On each insulator can be established/installed one or two current transformers [L. 19-1].

In linear conclusion/output it can be built in to three current transformers.

The distinctive special features/peculiarities of built-in current transformers are simplicity of device/equipment and small cost/value, caused by the use of insulation of apparatus. Furthermore, they do nct require the special place in distributor, which reduces the cost of the latter. To deficiencies/lacks in them can be attributed low power and comparatively low accuracy, especially with small primary currents.

Since the operating current of installation sometimes considerably differs from the rated current of the apparatus which is built in current transformer, then for obtaining different transformation ratios secondary windings of built-in current transformers are supplied with branchings. Sometimes secondary windings of two built-in current transformers connect in series, which allows with the same class of precision to increase burden of transformer doubly. With small operating currents is applied parallel connection of secondary windings, which increases the accuracy of measurement.

Chapter Twenty.

VOLTAGE TRANSFORMERS.

20-1. General information.

Voltage transformers apply in the installations of alternating current by voltage 380V even above for the feed of the parallel coils of measuring meters and relay of protection. The primary winding of voltage transformer (Fig. 20-1) they connect in parallel to network/grid, and to secondary winding connect the parallel coils of instruments and relay.

The conversion of voltage by voltage transformer characterizes its nominal transformation ratio (it is designated on its panel):

$$k_{\text{ном}} = \frac{U_{1\,\text{ном}}}{U_{2\,\text{ном}}} \approx \frac{w_1}{w_2}, \qquad (20\text{-}1)$$

where $U_{1\,\text{ном}}$ and $U_{2\,\text{ном}}$ - the nominal primary and secondary voltages;

w_1 and w_2 - number of turns of primary and secondary windings of voltage transformer.

Voltage transformers are manufactured with such transformation ratios, with which their nominal secondary voltage is equal 100V or

$100/\sqrt{3}$ V.

Secondary windings of voltage transformers connect up triangle or into star and so that the secondary interphase voltage would be equal to 100V.

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Therefore the parallel coils of instruments and the relays, intended for connection to voltage transformers, are manufactured to voltage 100V. Such instruments and relay have very simple construction/design, are cheap, reliable and they can possess high accuracy measurements.

The start of instruments and relay through voltage transformers provides safety of their maintenance/servicing and it makes it possible to establish/install them in considerable distance from the circuits of high voltage, in this case are utilized the jumpers and the cables of the small sections: from 1.5-2.5 to 6 mm².

For the same reasons which were presented in § 19-1, secondary windings of voltage transformers in installations by voltage 500V and are above compulsorily grounded (Fig. 20-1).

For convenience in the operation the measuring meter, connected to voltage transformer, must show or consider the real values of the primary circuit: voltmeter - the actual stress of circuit (primary), wattmeter - available power, counter - real quantity of electric power, etc. Is reached this by the fact that the scales of measuring meters are calibrated in connection with the specific transformation ratio of voltage transformer, which is indicated on dial face.

Principle of device/equipment, circuit diagram and special feature/peculiarity of the work of voltage transformers the same as power transformers. However, the power of voltage transformers is small and composes usually several ten or hundreds of volt-amperes. In this case their load in the majority of the cases is permanent.

The most important requirement, presented to voltage transformers, is the requirement of the accuracy of measurement, it is necessary that they would introduce least possible error into measurements.

Voltage transformers introduce into measurements two errors: error in the value of voltage (in transformation ratio) ΔU and the angular error δ.

Resorting to reasonings, by analogous presented in § 19-1 during

the derivation of formula (19-5), and utilizing expression (20-1), we can arrive at the following formula for determining the error in the value of voltage, expressed in percentages of the measured voltage U_1:

$$\Delta U\% = \frac{U_2 k_{\text{ном}} - U_1}{U_1} 100. \qquad (20\text{-}2)$$

An angular error in voltage transformer is called angle δ between the vector of primary voltage U_1 and the turned on 180° vector of secondary voltage $-U_2$ (Fig. 20-1).

An error in voltage transformer in the value of voltage introduces the error into readings of all measuring meters, and the angular error has a value only for instruments and wattmeter type relay, as this was indicated in § 19-1 in the relation to errors in current transformers.

Both errors in voltage transformer depend on its running-light current with increase in which they grow/rise. For reduction in current of idling, but thereby also errors, are manufactured voltage transformers with the cores, which possess least possible reluctance which is achieved by the use/application of transformer steel with high magnetic permeability, by the decrease of the length of magnetic circuit, by an increase in the cross-sectional area of core, and also by a decrease of the value of air gaps on the path of magnetic flux. Errors depend also on active and inductive winding impedances of

voltage transformer with decrease of which the errors decrease.

Magnitudes of error of voltage transformer depend on its use in operation. With an increase in burden S_2 both errors increase. With loading of burden (by decrease cos ϕ_2) especially considerably increases the angular error in voltage transformer.

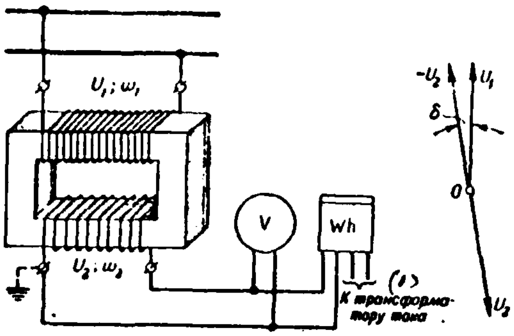

Fig. 20-1. Schematic of the device/equipment of single-phase transformer of voltage and vector diagram of voltages.

Key: (1). To current transformer.

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The considerable oscillations/vibrations of primary voltage also manifest themselves magnitude of error of voltage transformer. GOST [All-union State Standard] 1983-43 it is established/installed, that errors in voltage transformer do not exceed the permissible values only during the oscillation/vibration of primary voltage within limits of ±10o/o from $U_{1ном}$.

The classes of the precision of voltage transformers are characterized by the great ones permitted by the errors, indicated in Table 20-1.

The nominal power of voltage transformer with its work in this class of precision is called such load of transformer with which its errors do not exceed those established/installed for this class of precision (according to Table 20-1).

Voltage transformer can work in the different classes of precision depending on the value of its burden. To each class of precision corresponds the specific nominal power of voltage transformer.

For example, for voltage transformer of the type NOM-10 (voltage transformer single-phase with oil insulation on primary voltage 10 kV) are established/installed the nominal power: in the class of precision 0.5-50 VA, in class 1-80 VA and in class 3-200 VA. Hence it follows that if burden of voltage transformer $S_2 \leq 50$ VA, then it works with the errors, which do not exceed the values, established/installed for the class of precision 0.5. With burden it is more than 50 VA, but not more than 80 VA, voltage transformer works in the class of precision 1, while with burden in the limits of 80-200 VA - in the class of precision 3.

Is characterized voltage transformer by the highest class of

precision in which it can work (it is indicated in its certified/rating table).

Voltage transformers of class 0.2 are applied only for precise laboratory measurements.

For the start of attendant electric measuring instruments apply voltage transformers, which work in the class of precision not lower than 3 [L. 3-6, § I-6-3]. The calculated and monitor counters (see § 19-1) one should connect up voltage transformers of the class of precision 0.5.

For each voltage transformer is established/installed also the amount of the maximum (maximum) power, long permitted according to the condition of its heating.

The use of voltage transformer on maximum power is possible only for the feed of signal lamps, disconnecting coils of automata and other instruments and relay, for correct work of which does not have a value magnitude of error.

20-2. Diagrams of connections of voltage transformers.

By a number of phases are distinguished single-phase and

three-phase voltage transformers. Soviet plants construct single-phases transformer of voltage on all voltages to 500 kV inclusively, and three-phase - to voltages to 18 kV inclusively.

By a number of windings are distinguished two- and triple-wound voltage transformers. The latter, besides fundamental secondary winding, which uses for the feed of measuring meters and relay of protection, have even supplementary winding, intended for the start of the relay of the control/checking of the state of the insulation of network/grid and relay of protection from single-phase closings/shortings to the earth. These supplementary windings are placed on the same rods of magnetic system, as inducing windings of voltage transformer.

Fig. 20-2 gives the most commonly used diagrams of connections of voltage transformers. One single-phase transformer voltages (diagram a) apply in the installations of single-phase ones, and also three-phase ones, when it suffices to have interphase voltage only between two any phases (for the start of voltmeters, frequency meters, coils of the zero voltage of hand drives of switches, voltage relay, etc.).

On schematic b two single-phases transformer the voltages are connected into the open delay.

Table 20-1. Greatest permissible errors in voltage transformers (GOST 1983-43).

(1) Класс точности	(2) Наибольшие погрешности	
	(3) в напряжении, %	(4) угловая, *мин*
0,2	±0,2	±10
0,5	±0,5	±20
1	±1	±40
3	±3	(5) Не нормируется

Note. Errors in voltage transformers must not exceed the values, which correspond to their class of precision with a change in their load from 25 to 100o/o of nominal value, with a change in the primary voltage from 0.9 to 1.1 from nominal and with cos ϕ_2=0.8.

Key: (1). Class of precision. (2). Greatest errors. (3). in voltage. (4). angular, min. (5). It is not normalized.

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This diagram is suitable if necessary for the start of measuring meters and relay only on the interphase voltages (phase voltages of installation according to this diagram cannot be measured). It is applied in networks/grids with the ungrounded neutrals or with the neutrals, grounded through high-impedance resistors/resistances. If the power of two single-phases transformer of voltage is

insufficient, then sometimes switch on three single-phases transformer voltages into full/total/complete triangle.

On schematic c (without the windings, designated by dotted line) three single-phase double wound voltage transformers they are connected into star with the dead ground of the neutral of primary windings. This diagram makes it possible to measure the voltages between phases and the voltages of phases with respect to the earth/ground. In networks/grids with the ungrounded neutrals or with the neutrals, grounded through high-impedance resistors/resistances, this diagram apply only for control/checking the states of the insulation of network/grid with respect to the earth/ground (see Vol. 2, chapter 15) and for the connection of the instruments, which do not require the especially high class of the precision of voltage transformers - voltmeters, frequency meters, voltage relays, etc. The electric systems indicated can comparatively long work with the locked to the earth phase when the voltages of intact/uninjured/undamaged phases with respect to the earth/ground are raised to interphase voltage (chapter 5); therefore for connection on diagram c it is necessary to apply single-phases transformer of voltage on the nominal voltage, which corresponds to the interphase voltage of installation. In normal mode the primary windings of these voltage transformers constantly are located under phase voltage, i.e., in $\sqrt{3}$ the time of smaller than their nominal

voltage, in connection with which of an error in voltage transformers they can considerably exceed normal values. Therefore diagram c and should not be applied for the feed of wattmeters and counters.

For networks/grids by voltage 110 kV it is above, that work with dully grounded neutrals, are manufactured single-phase triple-wound voltage transformers whose primary windings are designed for the phase voltage of installation (diagram in Fig. 20-2c with the addition of the windings, traced by dotted line). In this case the primary windings of three single-phases transformer of voltage are also connected into star with the grounding of neutral, however, since they are designed for phase voltage, then diagram can be used for the start of any measuring meters.

Fundamental secondary windings connect up star and they utilize for the feed of measuring meters and relay of protection.

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Fundamental secondary windings connect up star and they utilize for the feed of measuring meters and relay of protection.

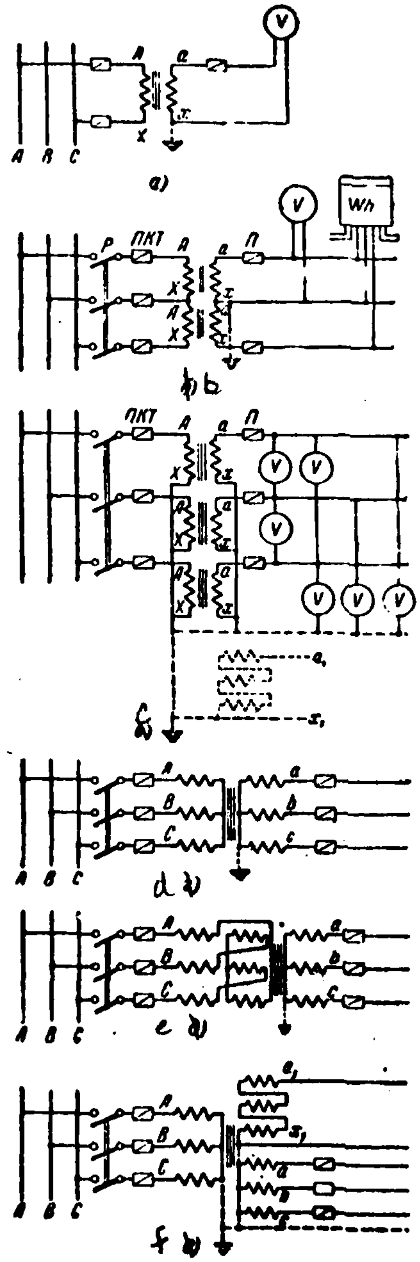

Fig. 20-2.

Fig. 20-2. Diagrams of connections of voltage transformers.

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Supplementary secondary windings of three phases connect up the extended triangle (windings are traced by dotted line). Since in normal mode vector sum of the phase voltages of three-phase system is equal to zero, the load voltage of extended triangle (a_1-x_1) is approximately/exemplarily equal to zero. During closing/shorting to the earth of one of the phases in the network/grid of primary load voltage of the extended triangle appears the voltage, equal to vector sum of the voltages of two intact/uninjured/undamaged phases (see Chapter 5). A number of turns of supplementary windings is such, that this vector sum of voltages within the limit proves to be equal to 100V. If we include/connect on the terminals/grippers of the extended triangle, for example, of voltage relay, then in the winding of latter/last current it will not normally be and the contacts of relay will be extended. During full/total/complete single-phase closing/shorting to the earth in the network/grid of highest load voltage of relay will appear the voltage 100V, and it will operate/actuate.

Fig. 20-2d and e shows the diagrams of connections of

three-phase tripivotal voltage transformers which can be used for measuring the interphase voltages of installation. For measuring the voltage of phases with respect to the earth/ground these voltage transformers it is not possible to utilize; therefore their primary windings do not have the brought-out neutrals. In diagram e is used compensated three-phase voltage transformer (type NTMK - voltage three-phase oil compensated), distinctive special feature/peculiarity which is the peculiar diagram of connection of the primary windings of three phases. In these voltage transformers the fundamental turns of the primary winding of each phase are connected with a small number of turns of another phase how is achieved the decrease (compensation) of angular error.

Thus, in three-phase networks/grids with the ungrounded neutrals or with the neutrals, grounded through high-impedance resistors/resistances, for the start of measuring meters and relay to interphase voltage it is possible to apply either the circuit diagram of two single-phases transformer into the open delay (diagram b), or three-phase transformer (diagrams d and e). Preference usually give up to diagram b with two single-phases transformer voltages, since they are more reliable than three-phase ones and their repair is cheaper and it is simpler. The nominal power of two single-phases transformer is more than the nominal power of one three-phase. The nonuniform charging of the phases of three-phase voltage transformer

leads to an increase in its errors.

In networks/grids with low currents the closings/shortings to the earth apply also three-phase triple-wound voltage transformers with the magnetic system, which has five rods - five-rod voltage transformers (diagram 5). In these voltage transformers the primary windings of three phases, the designed for phase voltage installations, connect up star and they ground. Fundamental secondary windings, also connected into star, utilize for the start of instruments to interphase or phase voltage. Supplementary secondary windings connect up the extended triangle and they utilize, as it is said above, for the control/checking of the state of the insulation of network/grid.

Thus, five-rod voltage transformers appear as universal, since they make it possible to measure the interphase voltages and to realize control of insulation state with respect to the earth/ground and relaying from single-phase closings/shortings to the earth (in more detail about the control of insulation state see Vol. 2, chapter 15).

The use/application of five-rod voltage transformers for the control of insulation state is more expediently than the use/application of three single-phases transformer of voltage, since

three-phase five-rod transformers simultaneously can be utilized for the start of any measuring meters and relay.

In installations witn voltage 380 and 500V voltage transformers most frequently connect only through safety fuses (Fig. 20-2a), while in the installations of large voltages - usually through disconnectors and safety devices/fuses (Fig. 20-2b, etc.).

Safety devices/fuses from the primary side of transformer serve for circuit protection from the consequences of short circuit during damage in transformer itself or in the section between safety devices/fuses and transformer. These safety devices/fuses do not shield voltage transformer from overloadings, since the rated current of their fuse links whose section is taken by smallest possible according to the conditions of mechanical strength, many times exceeds the insignificant rated current of primary winding.

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For the protection of voltage transformer from overloadings upon erroneous connections, and also from short circuits in all ungrounded wires, which go to instruments, are established/installed the safety fuses (P in Fig. 20-2b) or the small/miniature automata of maximum current.

Before voltage transformers it is most expedient to establish/install safety fuses with quartz filling of types PKT or PKTU, which are high speed, current-limiting and are capable of disconnecting the very large power of the short circuit (see Table P-12).

In the open distributors before voltage transformers 35 kV are installed horny safety fuses. Since the disconnecting ability of the latter is small, then before them compulsorily install the current-limiting resistors/resistances.

Voltage transformers 110 kV are above, and also busbar/tire connections to them are fulfilled with large reliability, why short circuits in them little are probable. Based on this, voltage transformers indicated connect up the collecting mains of installations only through disconnectors, without safety devices/fuses.

20-3. Constructions/designs of voltage transformers.

Soviet plants manufacture voltage transformers on all voltages to 500 kV inclusively. Depending on insulation are distinguished

voltage transformers with dry and oil insulation. Both those and others are fulfilled in accordance with natural air and oil-immersed natural cooler.

Air-immerseds transformer of voltage are applied only in the dry closed distributors. Their fundamental advantages: light weight, fire and explosion-proof character (there is no fuel oil). Soviet plants manufacture air-immerseds transformer of voltage for installations to 6 kV inclusively (table P-18): single-phase of the type NOS (voltage transformer single-phase dry), type NOSK (K - with the compensating winding) and three-phase tripivotal of the type NTS.

The tank transformers of the voltage of normal construction/design Soviet plants manufacture to voltages 3-35 kV (table P-18). Magnetic system with the windings of this transformer is placed in the welded steel tank, flooded by transformer oil. The outputs of windings are realized through porcelain wall entrance insulators, fastened/strengthened in steel cover/cap (Fig. 20-3).

To voltages 3-18 kV are manufactured voltage transformers single-phase of the type NOM (voltage transformer single-phase oil, Fig. 20-3), three-phase tripivotal of the type NTMK (K - that compensated) and three-phase five-rod of the type NTMI (Fig. 20-4). They all are intended only for internal installation and do not have

expanders (see Chapter 23); therefore in them under the head of tank it remains certain not filled by oil space.

To voltage 35 kV manufacture only single-phases transformer the voltages for the external installation of types NOM-35 and 3NOM-35 (3 - triple-wound with dead ground neutrals of primary windings, i.e., for connection on diagram in Fig. 20-2c, switching on the designated by dotted line connection in the extended triangle of supplementary windings). The tanks of these voltage transformers are equipped with expanders.

Cascade voltage transformers. With voltage 110 kV and above normal single-phases transformer the voltages with steel tanks and porcelain wall entrance insulators are obtained excessively bulky, heavy and expensive. Therefore for these voltages received wide acceptance cascade voltage transformers, assembled in porcelain jackets and not having wall entrance insulators.

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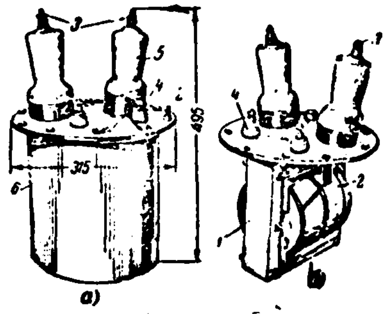

Fig. 20-3. Single-phase transformer of voltage of the type NOM-10 on 10 kV with oil cooling for internal installation. a) in the assembled form; b) cutting part. 1 - core; 2 - winding 10 kV; 3 - terminals/grippers of the primary circuit; 4 - conclusion/output of the secondary voltage; 5 - insulators; 6 - jacket.

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In usual voltage transformer primary winding insulate from core and secondary winding to total voltage of installation. In cascade voltage transformer the insulation is distributed evenly to the series/row of the steps/stages each of which is located only under certain part of the voltage of installation. This gives the large savings of insulation.

Cascade voltage transformer consists of the series-connected choke coils, connected between the phase and the ground (Fig. 20-5).

With dully grounded neutrals of the network/grid through all choke coils flows/occurs/lasts the identical current, proportional U_{Φ} to network/grid. The latter/last choke/throttle, connected with the earth/ground, has secondary winding. With change U_{Φ} in the network/grid changes load voltage of this secondary winding.

If secondary winding is extended (idling), then magnetic fluxes in the cores of all elements/cells of cascade/stage are equal and the voltage between them is distributed evenly. In the case, represented in Fig. 22-5a, to each element/cell of cascade/stage comes voltage $\frac{1}{2}U_{\Phi}$. After connecting electrically midpoint of the winding of each element/cell with core, we obtain, that the extreme turns of windings must be isolated/insulated from core only on $\frac{1}{4}U_{\Phi}$. At the same time cores must be isolated/insulated from each other and from housing. The latter is reached simply, since housing is fulfilled from porcelain. Thus, in this transformer the insulation of internal parts must be calculated not more as on $\frac{1}{2}U_{\Phi}$, instead of U_{Φ} in usual transformers.

If secondary winding is locked to measuring meters, then in it flows/occurs/lasts certain current, which creates the demagnitizing magnetic flux, as a result of which the resulting magnetic flux in the core of lower element/cell proves to be less than magnetic fluxes in the cores of other elements/cells. Because of this inductive

reactances of the elements/cells of cascade/stage will be different and voltage it will be distributed between them unevenly. For eliminating this will deposit to the cores of all elements/cells supplementary windings with an identical number of turns, connecting them contrarily (Fig. 20-5b). As a result of this any change of magnetic flux of one of the elements/cells causes the course of the cross currents (they are shown by rifleman/pointers), which demagnitize the cores of elements/cells with greater magnetic flux and which magnetize with smaller. Magnetic fluxes in cores will be approximately/exemplarily equal, and voltage on elements/cells will be distributed evenly. Each element/cell of cascade/stage has the independent two-rod magnetic circuit.

Cascade voltage transformers usually have two secondary windings: fundamental to voltage $100/\sqrt{3}$ V and supplementary to voltage 100V. For the feed of measuring meters and relay of protection is installed the group of three cascade transformers, connecting fundamental secondary windings in star, and supplementary - into the extended triangle (diagram c in Fig. 20-2).

Soviet plants manufacture cascade transformers by voltages 110 kV and higher (type NKF) for external installation. The general view of cascade transformer to voltage 110 kV is shown in Fig. 20-6. The schematic diagram of its connections is given in Fig. 20-5b. The phase voltage of installation composes $110/\sqrt{3} \approx 64$ kV.

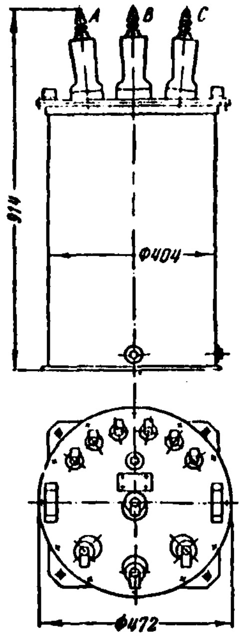

Fig. 20-4. Three-phase five-rod voltage transformer type NTMI-10 on 10 kV for internal installation.

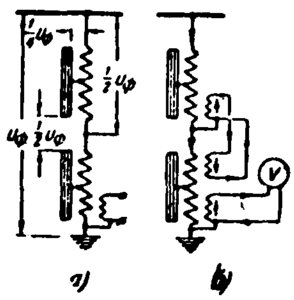

Fig. 20-5. Schematic diagrams of cascade voltage transformer on 110 kV.

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With two elements/cells and with the connections accepted internal insulation is fulfilled to voltage not more than 32 kV.

Porcelain housing 1, fastened/strengthened to trolley 5, is equipped with metal cap- expander 2 with oil meter tube with 4. Wire from the phase of circuit 110 kV they terminate 3, which is connected since the beginning of the primary winding and is built in directly the metallic expander. The latter, therefore, is located under voltage. The end/lead of primary winding is connected to the metallic trolley which reliably grounds (6 - outputs of secondary windings).

Cascade voltage transformers do not have wall entrance insulators, which sharply decreases their overall sizes, weight and cost/value.

For a characteristic let us note that if the total weight of normal voltage transformer on 110 kV (in metallic tank with wall entrance insulators, type NIOM-110) was 3,895 kg, then the weight of cascade voltage transformer of the type NKF-110 is only 1,360 kg, i.e., it is approximately/exemplarily 2.9 times less. Cost/value was respectively lowered approximately/exemplarily to 25o/o.

Cascade voltage transformers comprise from several identical elements/cells whose specific number, voltage-sensitive, they collect/build and connect up the specific sequence. For example, cascade transformer to voltage 220 kV they compose of four elements/cells of transformer on 110 kV. In this case the housing of the first consists of two porcelain covers of the same sizes/dimensions and transformer on 110 kV. All this considerably simplifies and reduces the cost of the production of cascade voltage transformers it facilitates their transport.

A deficiency/lack in cascade voltage transformers is their somewhat larger than errors, which increase with an increase in the number of elements/cells. Soviet cascade voltage transformers have a class of precision 1.

Combined voltage transformers and current. Possible to combine in one jacket single-phase transformer of voltage and current transformer, as it is schematically shown in Fig. 20-7a. Input and output of one phase for the connection of the primary winding of current transformer 1 easily is realized in one wall entrance insulator, since the insulation of the current-carrying rods must be carried out to a comparatively small voltage. Second wall entrance insulator is necessary for the connection of the primary winding of voltage transformer to the second phase or for connection into the

star of the primary "windings of three such voltage transformers.

In networks/grids with dully grounded neutrals and during the use/application of porcelain housing there is no need for in bulky wall entrance insulators (Fig. 20-7b).

20-4. Capacitor voltage dividers.

In the installations of very high voltages for the feed of the branch circuits of measuring meters and relay of protection instead of voltage transformers it is possible to utilize capacitor voltage dividers.

Capacitor voltage divider consists of several series-connected capacitors/condensers of identical capacity/capacitance, connected to the measured voltage. In electric systems with grounded neutrals by voltage 110 kV it is above, where predominantly and are applied capacitor voltage dividers, them are connected between the phase and the earth/ground (Fig. 20-8a).

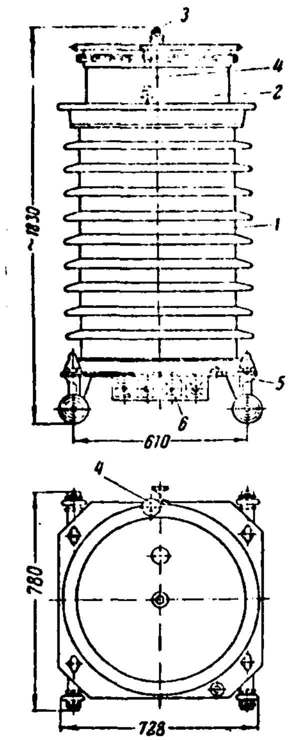

Fig. 20-6. Cascade voltage transformer of the type NKF-110 on 110 kV.

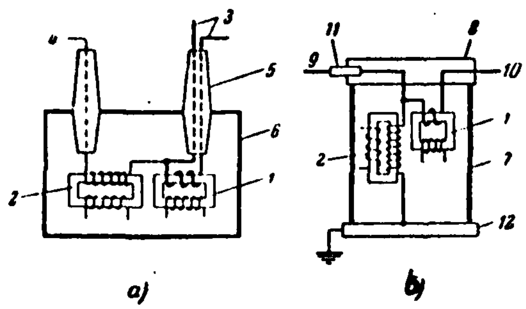

Fig. 20-7. Schematic diagrams of combined current transformers and voltage. a) in the metal casing; b) in porcelain jacket for systems with dully grounded neutrals. 1 - current transformer; 2 - voltage

transformer; 3 - conclusion/output from current transformer; 4 - conclusion/output from voltage transformer; 5 - two-rod wall entrance insulator; 6 - steel jacket; 7 - porcelain jacket; 8 - expander; 9 - isolated/insulated conclusion/output; 10 - conclusion/output, electrically connected with the expander; 11 - insulator; 12 - trolley or metallic base.

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With n capacitors/condensers in divider each of them is located under voltage $U_C=\frac{U_\Phi}{n}$, which usually composes several thousand volts.

Connecting electrostatic voltmeter (Fig. 20-8a), to the terminals/grippers of latter/last capacitor/condenser, it is possible to measure by it the voltage of installation with respect to the U_Φ earth/ground, since with change U_C, proportionally it changes and i.e. load voltage of voltmeter.

For the feed of the pressure coils of instruments and normal type relay to the terminals/grippers of latter/last capacitor/condenser they connect instrument transformer, which transforms voltages U_C of up to value 100V (Fig. 20-8b).

The accuracy of measurement with the aid of the voltage dividers

is small. Error in voltage reaches 6-10o/o, and angular to 90-120 min and even larger values, in this case the errors to large degree depend on the temperature of divider, value and character of its burden and series/row of other factors. Therefore capacitive voltage-dividers for precise measurements, but especially for the feed of counters electric power, do not apply. Them are utilized for the feed of those instruments and relay for which comparatively large errors do not have the vital importance: voltmeters, frequency meters, instruments of synchronization, voltage relay, etc. The feed of wattmeters is allowed/assumed when they serve only for determining the direction of the course of power in the locked network/grid (for example, in the ring of electric power lines).

As capacitor voltage dividers are utilized condenser types terminal of oil breakers and power transformers by voltage 110 kV and are above or the capacitors/condensers of high-frequency connection/communication on the wires of electric power lines.

Fig. 20-8c gives the schematic of device for measuring the voltage (in abbreviated form PIN) with the aid of condenser type terminal 1. As is known, the insulation of the current-carrying rod of 2 condenser/capacitor wall entrance insulators is fulfilled by the series/row of cylinders from Bakelite paper 3 with metallic separators 4 between them (from foil). Each pair of metallic rollers,

divided by the Bakelite paper, is cylindrical capacitor/condenser. The sizes/dimensions of cylinders are selected so that the capacitances of all capacitors would be identical. The external facing of latter/last capacitor/condenser is grounded. In parallel to latter/last capacitor/condenser they connect primary winding 5 PIN. Secondary windings two: one (6) to nominal voltage 110V the second (7) to $100/\sqrt{3}$ V. Secondary windings PIN of three phases connect just as secondary windings of single-phases transformer of voltage (Fig. 20-2c).

The decrease of errors PIN is achieved by controlling a number of turns of its primary winding. For the same targets is provided reactor by 8 with a variable number of turns. Capacitor/condenser 9 serves for the compensation for exciting current of transformer and inductive component of the current of burden, which also decreases the errors PIN.

Discharger (discharger/gap) 10 shields primary winding and reactor from overvoltages during short circuits in the terminals/grippers of secondary windings.

Permissible burden PIN is usually small and is only 10-50 VA.

All the equipment PIN is placed in the small steel tank, flooded

by transformer oil, which is fastened to Baku switch near its introductions/inputs (Fig. 17-4). PIN can be established/installed on three or during six introductions/inputs of switch.

The examined devices/equipment considerably cheaper than cascade voltage transformers and do not occupy the place in distributor.

The capacitors/condensers of high-frequency connection/communication on the wires of electric power lines are performed in the form of separate apparatuses in porcelain housings. The setting up of such capacitors/condensers it is possible to see on the drawings of distributors by voltage 110 kV even above, led in chapter 10 second volumes.

These capacitors/condensers simultaneously utilize for connection to the wires of the line of the transceivers of connection/communication and for the start of some relayings. Permissible burden of apparatuses of this type reaches hundreds of volt-amperes.

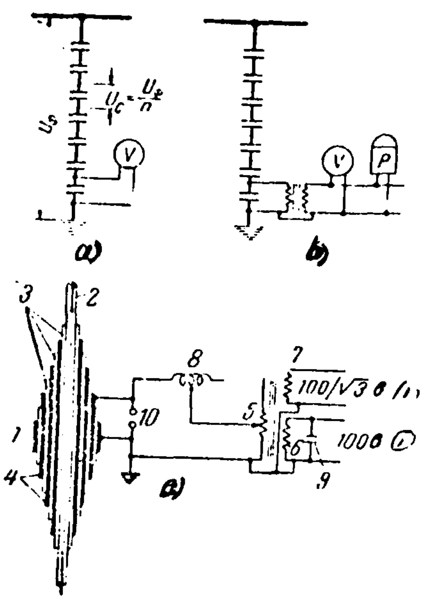

Fig. 20-8. Capacitor voltage dividers. a) the schematic of the connection of the electrostatic voltmeter; b) the schematic of the connection of normal instruments and relay with the use of auxiliary instrument transformer; c) schematic diagram PIN.

Key: (1). V.

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Chapter twenty one.

SELECTION OF ELECTRICAL APPARATUSES.

21-1. General conditions for the selecting of apparatuses from rating factors.

The reliable work of electrical plant can be provided only in such a case, when each adjustable on it electrical apparatus is correctly selected both according to the conditions of the normal mode of work and on working conditions during short circuits. Is examined below the selection of apparatuses from those rating factors, which are general/common/total for all apparatuses.

Selection of apparatuses on nominal voltage. The nominal voltage of electrical apparatus $U_{\text{апп.ном}}$ is called the indicated on its panel interphase voltage, numerically equal to the nominal voltage of that electrical network (§ 3-1), for a work in which it it is intended. At the same time all electrical apparatuses can how conveniently long time reliably work, also, with the voltage, on 10-15o/o more than nominal, which is called the maximum operating voltage of the

apparatus (it is indicated in the catalogs of apparatuses).

When selecting of apparatus on voltage it is necessary that the maximum long possible in the operation voltage of setting up would not exceed the maximum operating voltage of apparatus. If one considers that the maximum is working voltage of electrical devices (voltage on the collecting mains of stations and substations), as a rule, it does not exceed their nominal voltage (nominal line voltage) more than to 10-15o/o, then when selecting of electrical apparatuses on voltage it suffices to observe the condition:

$$U_{\text{апп.ном}} \geqslant U_{\text{уст.ном}}. \qquad (21\text{-}1)$$

The observance of this condition guarantees sufficient dielectric strength of the insulation of apparatus with all operating changes in the operating voltage of setting up.

Selection of apparatuses on the kind of setting up. If in the closed distributors apparatuses do not undergo any special atmospheric effects, then in the open distributors apparatuses are located under more severe conditions, since their insulation undergoes the effect of atmospheric residues/settlings, it is covered/coated with dust, products of escape from the chimney stacks of boiler rooms, etc. In accordance with this the apparatuses manufacture two types - for internal and external settings up.

In the case of the construction of the open distributors in the places, subjected to the intensive contamination, and also near the chemical plants, which saturate air by the detrimentally operating on insulation pairs of acids and by other chemical reagents, it is necessary to install apparatuses with increased dielectric strength of insulation, for which should be applied apparatuses with the insulators of special construction/design or selected to large nominal voltage. In a number of cases it can prove to be even advisable refuse from the open distributors and install those closed.

Selection of apparatuses on rated current. The rated current of electrical apparatus $I_{\text{апп.ном}}$ is called that greatest prolonged current with which the apparatus can work how conveniently long time, if the temperature of surrounding air does not exceed calculated value, which for apparatuses is accepted in the USSR equal to $\theta_0=35°C$. In this case heating all parts of the apparatus does not exceed the permissible value (see also § 3-3). The rated current of apparatus is indicated on its plant panel.

For the reliable work of apparatus it is necessary that its rated current would be equal or more than to the maximum prolonged current of the load of that circuit in which it was established/installed; therefore when selecting of apparatus on rated current must be observed the condition:

$$I_{\text{апп.ном}} \geq I_{\text{н.макс}}, \qquad (21\text{-}2)$$

where $I_{н.макс}$ - a maximum prolonged current of the load of circuit in which is installed the apparatus [taking into account the possible prolonged overloading of circuit - see also indications to formula (10-2) in § 10-2].

The overloading of apparatus by the current, exceeding its rated current at a calculated temperature of surrounding air of θ_0=35°C, and thereby the excess of the long permissible temperature of heating its parts, causes the sharp loss of life of apparatus as a result of a change in the mechanical and electrical properties of materials; therefore for the majority of apparatuses overloading with θ_0=35°C normally is not allowed/assumed.

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The corresponding indications about the permissible overloading are given in catalogs to apparatuses.

If apparatus must work at temperature of air of higher than 35°C, then as a result of the worse conditions for cooling it it is possible to load to current, somewhat smaller nominal.

Temperature excess of heating the current-carrying part of the apparatus is proportional to the square of the current of load; therefore

$$\frac{I^2_{\text{раб}}}{I^2_{\text{апп.ном}}} = \frac{\vartheta_{\text{доп}} - \vartheta'_0}{\vartheta_{\text{доп}} - 35^\circ},$$

whence

$$I_{\text{раб}} = I_{\text{апп.ном}} \sqrt{\frac{\vartheta_{\text{доп}} - \vartheta'_0}{\vartheta_{\text{доп}} - 35^\circ}}, \quad (21\text{-}3)$$

where $I_{\text{раб}}$ - the permissible operating current of apparatus with $\vartheta'_0 > 35^\circ C$;

$\vartheta_{\text{доп}}$ - the long permissible temperature of heating apparatus.

Equipment of normal construction/design can work at temperature of surrounding air not more than +60°C and not less than -40°C.

If the maximum temperature of the which surrounds apparatus air is less than 35°C, then as a result of the best conditions for cooling the long let-go current can be somewhat increased. For example, according to the data of plants, at $\vartheta'_0 < 35^\circ C$ and the greatest permissible operating current of high-voltage switches, disconnectors and current transformers it is possible to increase of calculation by 0.5 $I_{\text{апп.ном}}$ by each degree of a decrease in the temperature of air lower than 35°C, but in all it is not more than to

200/0 $I_{\text{ном}}$.

Under the maximum temperature of surrounding air it is necessary to understand the greatest temperature of air in the site of installation of apparatus, measured at a distance of 1-2 m from the middle of its housing and by the duration not less than 0.5 h.

21-2. Checking electrical apparatuses to the actions of short-circuit currents.

For checking electrical equipment to stability during short circuits it is necessary to know the great possible value of the short-circuit current which can flow/occur/last over this element/cell of electrical plant. The practical methods of calculation of short-circuit currents are presented in chapter 6. There are in detail shown those conditions for the work of electrical plant during which the short-circuit current has great value. In § 6-3 are given the indications about the composition of network of the setting up using which are designed short-circuit currents.

Here we will additionally examine selection on network of the calculation points of short circuit, and also determination of the calculated duration of the course of short-circuit current. After this let us examine the general conditions of checking the

apparatuses to stability during short circuits. The selection of the disconnecting apparatuses according to the disconnecting ability is presented below in § 21-3.

Selection of the calculation points of short circuit and calculated duration of the course of short-circuit current. The calculation points of short circuit should be outlined on network of setting up so that about selective electrical equipment would flow the greatest possible short-circuit current. The duration of the course of current is defined, as noted in § 7-2, by the time of action of fundamental relaying, shielding the damaged element/cell of setting up, and by the time of action of the switch: $t=t_{осн}+t_{в}$. This time is necessary for checking electrical equipment to thermal resistance during short circuits.

In the form of an example let us examine the selection of some calculation points in the diagram of Fig. 21-1. Let us first of all note that the circuits of generators and synchronous condensers in power approximately/exemplarily 1000 kW and above and power transformers power 7500 kVA and more normally supply with special high speed relayings (differential protection or current cutoffs; cm, Vol. 2, chapter 13), which have small triggering time, approximately/exemplarily 0.1-0.2 s. These protection are fundamental protection from short circuits for the elements/cells of setting up

indicated.

For the selection of electrical equipment in the circuit of generator, for example G-1, is sufficient to outline two points of the short circuit: K-1 and K-2. During short circuit at point K-1 over electrical equipment of generator branching flows/occurs/lasts the current short from generator G-2 and systems, while during short circuit at point K-2 only short-circuit current from generator G-1.

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Obvious that at the identical power of current generators of short circuit from generator G-2 and systems are more; therefore all the equipment of generator should be selected on this current. Calculation point is K-1. The duration of the course of short-circuit current is equal to the time of action of high speed (differential) relaying of generator plus the tripping time of switch V-1.

Calculation point for checking to the actions of the short-circuit current of the collecting mains of station is point K-3, since in this case in the nearest to the place of closing/shorting section of collecting mains (section ab) flows/occurs/lasts short-circuit current from both of generators and system. During this damage works relaying of busbars and are

disconnected switches V-1, V-3 and V-4.

Electrical equipment and circuits of the transformer of its own needs T-1 must be checked to short-circuit current, flowing into point K-4 from both of generators and system. It is obvious that this current is equal to short-circuit current during damage on collecting mains at point K-3. The duration of the course of short-circuit current in the case in question is determined by the time of action of fundamental relaying of transformer T-1 and by the tripping time of switch V-2.

It is obvious that for checking electrical equipment on the side of the secondary voltage of the transformer of its own needs must be outlined the corresponding point of short circuit at this voltage.

Sectionalizing switch V-3 and established/installed in its circuit apparatuses should be checked against the short-circuit current, which flows into point K-5 from generator G-2 and from the system through the transformer T-3 with off transformer T-2. It is not difficult to be convinced that this will be the greatest possible short-circuit current for the circuit of sectionalizing switch. The time of the course of short-circuit current is determined by the time of action of the protection of the collecting mains of station and by the tripping time of switch V-3.

Electrical equipment in the circuit of the primary voltage of the step-up transformer T-2 (from the collecting mains of generator voltage to transformer T-2) should be checked against larger of the short-circuit currents, which flow into point K-6 or into point K-7.

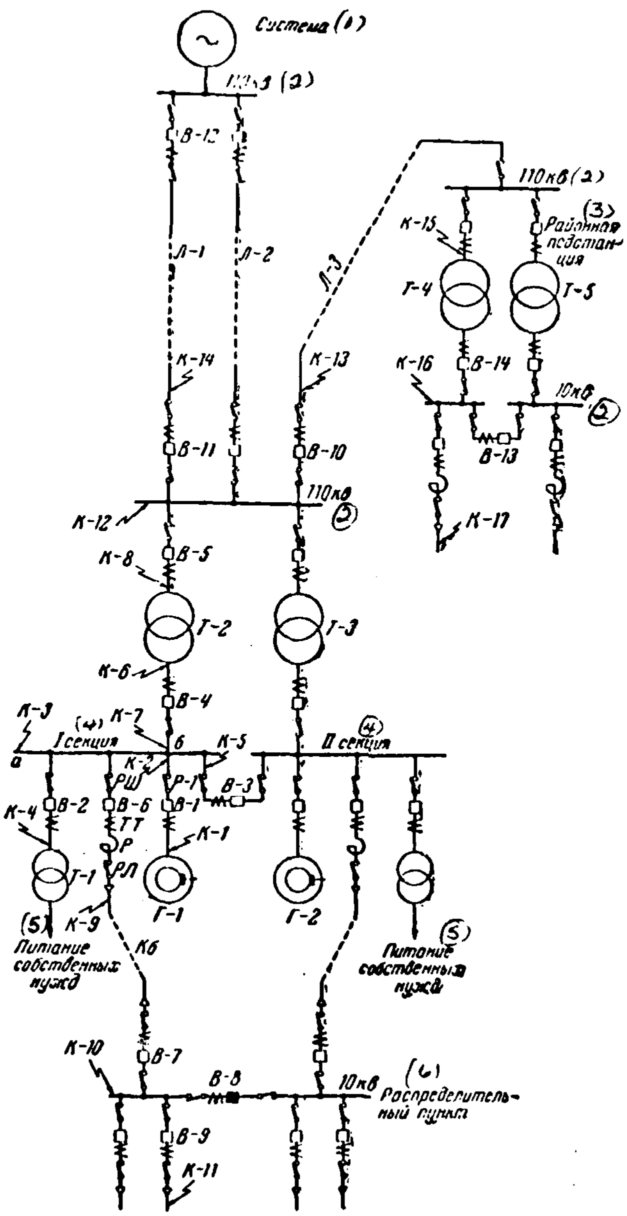
Система (1)
(2)
В-12
Л-1
Л-2
Л-3
110кВ (2)
К-15
(3) Районная подстанция
Т-4
Т-5
К-16
В-14
10кВ (2)
В-13
К-17
К-14
К-13
В-11
В-10
110кВ (2)
К-12
К-8
В-5
Т-2
Т-3
К-6
В-4
К-3
(4) I секция
К-7
б
К-5
(4) II секция
а
К-2
РШ
Р-1
В-3
К-4
В-2
В-6
В-1
ТТ
Р
К-1
Т-1
РЛ
Г-1
Г-2
(5) К-9
Кб
Питание собственных нужд
(5) Питание собственных нужд
К-10
В-7
В-8
10кВ
(6) Распределительный пункт
В-9
К-11

Fig. 21-1.

Fig. 21-1. Line diagram of power plant to the explanation of the selection of design conditions and for example of 21-1.

Key: (1). System. (2). kV. (3). District substation. (4). section. (5). Feed of its own needs. (6). Distribution point.

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It is easy to be convinced that under conditions of the diagram in question about electrical equipment indicated large short-circuit current flows during damage at point K-6 and on the assumption that the switch V-5 from the side of secondary voltage 110 kV is disconnected (short-circuit current of the generators of station plus short-circuit current from the system through T-3). This case of short circuit at point K-6 is feasible at the moment of the start of transformer T-2 under voltage by switch V-4. Analogously for the selection of electrical equipment in section from T-2 to collecting mains 110 kV the calculated case is short circuit at point K-8 with off switch V-4, i.e. at the moment of the start of transformer under voltage by switch V-5 (short-circuit current from system plus short-circuit current from the station through one transformer T-3). In both dismantled/selected cases the duration of short circuit is equal to the time of action of the high-speed protection of

transformer plus the tripping time of the corresponding switch.

In settings up with the dual system of collecting mains (Fig. 3-4) when selecting of design conditions for a bus-connecting switch should be considered its use for start under the voltage of the stand-by system of collecting mains. If at the moment of the start of bus-connecting switch on stand-by busbars is created short circuit, then through it will flow/occur/last short-circuit current from all supplies of power (as into point K-3). To this current must be calculated bus-connecting switch and entire established/installed in its circuit electrical equipment. One should also consider that with the fulfillment of process/operation indicated above relaying of bus-connecting switch must be controlled to action without time element (to the smallest possible period of action).

Electrical equipment in the circuit of the waste/exiting line without reactor is checked against short-circuit current during damage at the very beginning of the waste/exiting line, it is analogous how this was shown in the relation to equipment in the circuit of the transformer of its own needs T-1 (point K-4). In other words, equipment in the circuit of the waste/exiting line must be checked to the current, equal to short-circuit current on the collecting mains of setting up.

Electrical equipment of the reacted cable line (disconnectors busbar/tire RSh and linear RL, switch V-6, current transformers TT, reactor R, busbar, insulators, cable) checks against short-circuit current during damage after reactor at point K-9, i.e., at the very beginning of the cable of line, and on the time of action of relaying of line plus the tripping time of the switch of line [L. 3-6]. In this case necessary is the use/application of a reactor with the isolated/insulated turns and fulfillment the busbars of the section between the switch and the reactor.

Thus, when selecting of electrical equipment of the reacted cable line one ought not to assume the possibility of short circuit to linear reactor. Operating experience showed that as a result of comparatively small length of section from busbar/tire disconnector to reactor, and also very reliable fulfillment and good maintenance/servicing the short circuits in this section little were probable. On the other hand, produced by Soviet plants concrete reactors with the isolated/insulated winding are very reliable and with good care of them of short circuits in them also it is not.

At the same time the selection of electrical equipment of linear branching on short-circuit current to reactor, to the numerically equal to short-circuit current on the collecting mains of setting up, would lead to the need for establishing in all waste/exiting lines

the very heavy and expensive apparatuses, calculated for very large short-circuit currents. This solution technically and economically is not justified.

The especially critical part of the setting up are its collecting mains, since from the reliability of their operation to a considerable degree depends the steadiness of the work of an entire setting up. Taking into account this, the section of the set of tires of linear branching from collecting mains to busbar/tire disconnector, and in the presence of the shelves, which divide collecting mains and busbar/tire disconnectors (Vol. 2, chapter 8) to wall entrance insulators in these regiments and wall entrance insulators themselves should be checked on short-circuit current on collecting mains, i.e., without taking into account the current-limiting action of reactor, and on the time of action of relaying of the busbars of setting up.

Of shown the diagram in Fig. 21-1 distribution point in network/grid 10 kV is supplied by two cable lines with normally off sectionalizing switch V-8; therefore entire electrical equipment of point/item must be checked to short-circuit current, flowing into point K-10 or, which is the same thing, into point K-11 which is somewhat less than the short-circuit current at point K-9 due to the resistor/resistance of the cable of line.

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The duration of short circuit is determined taking into account the time of action of relaying in the appropriate circuit of distribution point.

Let us examine the selection of calculation points at voltage 110 kV. Collecting mains 110 kV and electrical equipment in the circuit of line L-3 must be checked on short-circuit current on collecting mains 110 kV, i.e., to flowing into point K-12 or, which is the same thing, into point K-13. The worse conditions will be upon start of both transformers T-2 and T-3 and both lines L-1 and L-2.

Electrical equipment of the circuit of the line of communications with system, for example L-1, must be checked on short-circuit current, flowing into point K-14 from the station through both transformers T-3 and T-4, also, from system only through another line of communications, for example L-2, i.e., into the assumptions that the line L-1 on the side of system is disconnected by switch V-12. Under this condition through the switch V-11 and other equipment of line will flow/occur/last the greatest short-circuit current.

Calculation point for checking to the stability of electrical equipment in all circuits of the side 110 kV of district substation is point K-15. Flowing into this point short-circuit current somewhat less than the short-circuit current at point K-13 due to the resistor/resistance of line L-3.

Design conditions on the secondary side of district substation depend on the normal mode of sectionalizing switch V-13. If normally transformers work separately (V-13 is disconnected), then electrical equipment in the circuit of transformer and collecting mains must be checked against short-circuit current, flowing into point K-16 through one transformer of substation.

In the case of the multiple operation of transformers T-4 and T-5 (V-13 is normally connected) collecting mains must be checked against short-circuit current, flowing into point K-16 with the multiple operation of transformers, and electrical equipment in the secondary circuit of transformer, switch V-14, etc. - with the separate work of transformers, i.e., with off V-13, since this mode/conditions of short circuit for the equipment of transformer will be most heavy.

If the waste/exiting lines of substation are not reacted, then their electrical equipment must be checked in terms of the same values of short-circuit currents, as the collecting mains of secondary voltage.

On design conditions for reacted of lines it spoke above (calculation is point K-17).

Analogously are selected design conditions also for other, not examined above elements/cells of electrical stations and networks/grids.

Checking electrical apparatuses to electrodynamic stability. Apparatus is considered as electrodynamically stable, if with the course on it of impact short-circuit current in it it is not observed any residual strains of the parts, which block its further exact work. Furthermore, must not be the sticking of contacts.

Electrodynamic stability of apparatuses is characterized by manufacturing plants by maximally let-go current $i_{макс}$ (amplitude value), called also the current of electrodynamic stability which must not be exceeded under any operating conditions of apparatus. By the greatest possible in operation current is impact short-circuit current; therefore the condition for the electrodynamic stability of

apparatus it is:

$$i_{макс} > i_{y}^{(3)}, \qquad (21\text{-}4)$$

where $i_{y}^{(3)}$ - a calculated impact current of three-phase short circuit in the circuit, for which is selected the apparatus.

To electrodynamic stability it is possible not to check the apparatuses, shielded by safety fuses with rated current to 60 A inclusively, but by the current-limiting safety devices/fuses (chapter 14) with any rated current of them [L. 3-6].

Checking apparatuses to thermal resistance. Thermostable is that apparatus whose all parts with the course on them of short-circuit current are not heated above established/installed by norms maximum short-term temperature.

The thermal resistance of apparatuses is characterized by plants by the current of thermal resistance I_t, i.e. by such current which during to preset time t (usually 1; 5 or 10 s) heats all parts of the apparatus not higher than established/installed for it by norms maximally permissible short-term temperature.

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Checking apparatus to thermal resistance consists in the

comparison of that permissible quantity of heat $Q_{доп}$, which can be short-term isolated in apparatus without the fear of its destruction, with that quantity of heat $Q_{кор}$, which is separated/liberated in actuality by short-circuit current for the time of its course, i.e.

$$Q_{доп} \geqslant Q_{кор}.$$

On the other hand,

$$Q_{доп} \equiv I_t^2 t \overset{(1)}{и} Q_{кор} = I_\infty^2 t_\Phi.$$

Key: (1). and.

Hence the condition for thermal resistance can be written thus:

$$I_t^2 t \geqslant I_\infty^2 t_\Phi \; [\overset{(1)}{ка^2 \cdot сек}]. \qquad (21\text{-}5)$$

Key: (1). kA²•s.

To thermal resistance it is possible not to check the apparatuses, shielded by safety fuses, independent of their type and rated current.

21-3. Selection of the separate types of electrical apparatuses.

Safety fuses select on: 1) to the nominal voltage; 2) to the rated current; 3) to the kind of setting up (external or internal); 4) to the design; 5) to the maximum disconnected current (maximum disconnected power).

Safety devices/fuses with the filling with quartz sand can be utilized only in networks/grids with the nominal voltage, which corresponds to the nominal voltage of the safety device/fuse (it is not possible, for example, safety device/fuse on 10 kV to apply in networks/grids 6 kV).

The maximum disconnected current of safety fuse $I_{откл.пр}$ with this voltage is called the great value of the short-circuit current of network/grid, with which is guaranteed the reliable work of safety device/fuse.

The high speed (current-limiting) safety fuses with quartz filling, etc. not only considerably limit short-circuit current, but because of the high effective resistance of arc increase $\cos\varphi_к$, drawing it nearer unity. Therefore when selecting of such safety devices/fuses it is possible not to consider aperiodic component/term of short-circuit current and to proceed from the condition:

$$I_{откл.пр} \geqslant I''^{(3)} \qquad (21\text{-}6)$$

or

$$S_{откл.пр} \geqslant S''^{(3)}. \qquad (21\text{-}6a)$$

Additionally is selected the fuse link on the rated current which can differ from the rated current of safety device/fuse.

Switches by voltage of up to 1000V select on: 1) to the nominal

voltage; 2) to the rated current; 3) to a number of poles; 4) to design (with central handle or rigging, with the connection of wires from the front or from behind, on insulating plate/slab or without plate/slab, etc.). In catalogs are given the indications, what operating currents can disconnect the switches of different types and design.

Automata additionally are selected on: 1) the kind of current (for the settings up of direct or alternating current); 2) to necessary ranges of adjustment of current and tripping time, if the latter is provided for; 3) to the maximum disconnected current.

When selecting of automata on the maximum disconnected current must be observed the condition [L. 3-6]:

for the high speed automata with the time of action 0.02 s and less

$$I_{\text{отк.пр}} \geq I_{y}^{(3)}, \qquad (21\text{-}7)$$

where $I_{y}^{(3)}$ - the effective value of the current of three-phase short circuit during the first period (see § 6-5);

for automata with action time it is more than 0.02 s

$$I_{\text{отк.пр}} \geq I''^{(3)}. \qquad (21\text{-}7a)$$

The automata, selected on the maximum disconnected current, can

be considered electrodynamically and thermostable during short circuits.

Disconnectors are selected on: 1) to the rated current; 2) to the nominal voltage; 3) to the kind of the setting up; 4) to design, and then they check against electrodynamic and thermal resistance.

Switches by voltage above 1000V select on: 1) to the nominal voltage; 2) to the rated current; 3) to the kind of the setting up; 4) to the design; 5) to the disconnected current or the disconnected power.

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The disconnecting ability of switches by voltage above 1000V is characterized with the nominal voltage of switch by its nominal disconnected current $I_{отк.ном}$ or by nominal disconnected power $S_{отк.ном}$, (see § 17-1), and with the voltage, different from the nominal voltage of switch, by disconnected current $I_{отк}$ or by disconnected power $S_{отк}$, which are given in catalogs to switches or in reference tables (Table P-14).

The real current which disconnects switch during short circuit, define as the effective value of the current of circuit at

moment/torque the beginnings of the disagreement of the arcing contacts of switch. Therefore in general when selecting of switch according to the disconnecting ability it is necessary to observe the condition so that the current of the cutoff/disconnection of switch $I_{отк}$ with this voltage of setting up would not be the less effective value of the short-circuit current of the circuit $I_{кt}$, of the referred to moment/torque disagreement of the arcing contacts of the switch:

$$I_{отк} \geqslant I_{кt} \quad (21\text{-}8)$$

Estimated time t, equal to time with the moment/torque of the onset of short circuit to the moment/torque of disagreeing the contacts of switch, is determined by the time of action of relaying $t_{защ}$ and by the proper time of the action of switch $t_{с.в}$ (§ 17-1):

$$t = t_{защ} + t_{с.в}.$$

Time $t_{защ}$ depends on the type of the used protection; for contemporary high speed relayings $t_{защ} = 0{,}02 - 0{,}05$ s.

The proper time of the action of the majority at present of the high-voltage switches used is $t_{с.в} = 0{,}04 \div 0.12$ s.

Short-circuit current $I_{кt}$ is determined by calculated curves (Fig. 6-25, 6-26). If t>0.1 s, then aperiodic component/term of short-circuit current is possible not to consider and to accept $I_{кt} = I_{пt}$, where $I_{пt}$ - periodic component/term of short-circuit current, determined according to calculated curve for time t.

But if t$\leqslant$0.1 s, then they consider both components of short-circuit current and determine $I_{\kappa t}$ by formula (6-37), after determining preliminarily $I_{\Pi t}$ by calculated curves, and i_{at} - according to formula (6-31).

In our designed practice when selecting of switches according to the disconnecting ability accept to proceed from the condition that the circuit is equipped with relaying with minimum action time. Then, taking into account the characteristics of switches by voltage above 1000V, manufactured at present with Soviet plants, accept t=0.1 s, i.e., they proceed from disruption by the switch of current $I_{\kappa t-0.1}$, which can be determined, being guided by formula (6-37):

$$I_{\kappa t-0,1}=\sqrt{I^2_{\Pi t-0,1}+i^2_{at-0,1}}.$$

Computations show that with sufficient accuracy it is possible to accept

$$I_{\kappa t-0,1}\approx I''.$$

Then when selecting of switch according to the disconnecting ability must be observed is the condition:

$$I_{\text{отк}}\geqslant I''. \qquad (21\text{-}9)$$

The same recommendation give PUE [1. 3-6].

If switch is selected by the disconnected power, then should be

observed the condition:

$$S_{отк} \geqslant S''. \qquad (21\text{-}10)$$

Current I_{kt} or I'' and power S'' should be determined during three-phase short circuit.

The selected switch is checked against electrodynamic and thermal resistance.

Drives to switches are selected on catalogs to the switches in which the manufacturing plants give indications about the recommended types of drives (tables P-14 and P-16).

It is necessary to consider advantages and disadvantages in different types of drives (chapter 18), and also kind of current and source power of the operational current which to assumed utilize for the feed of drives.

Transformers of current select on: 1) to the nominal voltage; 2) to the nominal primary current; 3) to nominal secondary current (if $I_{2\,ном} \neq 5$ A); 4) to the kind of the setting up; 5) the construction/design; 6) to the class of precision and to burden.

For determining burden of current transformer preliminarily compose trilinear diagram the connections to them of measuring

meters.

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Depending on type and designation/purpose of instruments they install, in what class of precision must work current transformers. Then on catalogs to electric measuring instruments (table P-19) is found the resistor/resistance of the consecutive coils of instruments, connected to current transformers, and according to formula (19-2) they determine burden of most loaded current transformer.

Inductive reactance of the consecutive coils of measuring meters and jumpers is insignificant and it it is possible not to consider, then:

$$z_з \approx r_з = \Sigma r_{приб} + r_{пров} + r_{конт} \; [ом], \quad (21\text{-}11).$$

where $\Sigma r_{приб}$ - total effective resistance of the consecutive coils of the instruments;

$r_{пров}$ - the effective resist_nce of the coupling drives;

$r_{конт}$ - resistor/resistance of all contacts of circuit.

If on the consecutive coils of measuring meters is known the

required by them power, then, without taking into account inductive reactance of instruments and wires, it is possible to determine the power, consumed in the secondary circuit of current transformer:

$$S_{з} \approx P_{з} = \Sigma S_{приб} + I^2_{2ном} r_{пров} + + I^2_{2ном} r_{конт} = I^2_{2ном} r_{з}. \qquad (21\text{-}12)$$

So that current transformer would work in the selected class of precision, it is necessary to observe the condition:

$$z_{2ном} \geqslant z_{з} \overset{(1)}{\text{или}} S_{2ном} \geqslant S_{з}, \qquad (21\text{-}13)$$

Key: (1). or.

where $z_{2ном}$ and $S_{2ном}$ - respectively nominal load or nominal power of current transformer with its work in that class of precision which is necessary for the adjustable instruments.

Contact resistance $r_{конт}$ they take as the usually equal to 0.1 ohms.

For determining the section of jumpers they enter as follows. Is determined burden of most loaded current transformer without taking into account jumpers, i.e.

$$\Sigma r_{приб} + r_{конт} \overset{(1)}{\text{или}} \Sigma S_{приб} + I^2_{2ном} r_{конт}$$

Key: (1). or.

and then is found the maximum possible resistor/resistance of jumpers

during which current transformer will work in the class of the precision accepted:

$$r_{\text{пров}} = z_{2\,\text{ном}} - (\Sigma r_{\text{приб}} + r_{\text{конт}})$$

or

$$r_{\text{пров}} = \frac{S_{2\text{ном}} - (\Sigma S_{\text{приб}} + I^2_{2\text{ном}}\, r_{\text{конт}})}{I^2_{2\text{ном}}}. \quad (21\text{-}14)$$

Section of the wires

$$s = \frac{l}{\gamma\, r_{\text{пров}}}.$$

Accept near larger standard section, but according to the condition of mechanical strength not less than 1.5 mm² with wires or cables with copper veins/strands even 2.5 mm² - with aluminum veins/strands [L. 19-2], and when, among the connected instruments, counter is present, it is not respectively less than 2.5 and 4 mm² [L. 3-6]. Specific conductivity with copper veins/strands they accept 53 m/Ω•mm², and with aluminum strands [1] 32 m/Ω•mm².

FOOTNOTE [1]. On electrical stations and substations in power with respect to 5 MW and 5 MVA and more should be applied control cables with copper veins/strands. In other installations it is possible to apply cables and wires with aluminum veins/strands, but when all apparatuses, instruments and setting terminals/grippers are equipped with the contacts, intended for the direct connection of aluminum strands [L. 19-2]. ENDFOOTNOTE.

With one current transformer under the length of wires l should be understood the length of straight/direct and return conductor $l=2l_1$ (Fig. 19-3a). With the connection of three current transformers into star (Fig. 19-3b), when in neutral conductor no current there is, take length wires one-way trip $l=l_1$. If two current transformers are connected into incomplete star (Fig. 19.3c), then in return conductor flows/occurs/lasts the current, out of phase angle of 60° from current in go conductor. Because of this the vectors of a voltage drop in straight/direct and return conductor are shifted also angle of 60°. Hence the power, lost in the jumpers:

$$S_{пров}=\sqrt{3}U_{пров}I_{2ном}=$$
$$=\sqrt{3}r_{пров}I^2_{2ном}=\frac{\sqrt{3}l_1}{\gamma s}I^2_{2ном}.$$

Consequently, with the connection of current transformers into incomplete star it is necessary to accept $l=\sqrt{3}l_1$.

Selected current transformer is checked against electrodynamic and thermal resistance during short circuit.

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The electrodynamic stability of current transformers they characterize by the electrodynamic multiplicity, equal to the relation of the maximum let-go current to the amplitude of the primary rated current:

$$K_{дин} = \frac{i_{макс}}{\sqrt{2}\, I_{1ном}}.$$

Being guided by general condition (21-4) for the electrodynamic stability of apparatuses, we can write the following condition for the electrodynamic stability of current transformer:

$$K_{дин} \sqrt{2}\, I_{1ном} \geq i_y^{(3)} . \qquad (21\text{-}15)$$

With the course of impact short-circuit current on the cap/hood of the insulator of current transformer operates the force, caused by interaction of currents in the connected to it busbars and which depends on the distance between phases a and distances l from the cap/hood of the insulator of current transformer to the nearest stand-off insulator. Being guided by the indications of §7-1 and §9-5, this force can be determined by the formula:

$$F_{расч} = 0{,}5 \cdot 1{,}76\, i_y^2 \frac{l}{a} 10^{-2}\ [кГ]^{(1)} \quad (21\text{-}16)$$

Key: (1). kgf.

where coefficient of 0.5 considers the distribution of the force of interaction at the length of busbars l between the cap/hood of current transformer and nearest to it stand-off insulator (i_y in kA).

The obtained effort/force must not exceed the mechanical load, permitted on the cap/hood of the insulator of current transformer (it is indicated in catalogs, see also Table P-17).

For some current transformers (for example, for passage single-turns transformer of the type TPOF) the permissible mechanical load on insulator is not indicated, but the multiplicity of dynamic stability $K_{дин}$ is assigned for the specific values of a and l busbar/tire construction/design. If the sizes/dimensions of busbar/tire construction/design differ from those accepted in catalog, then with respect must be changed the multiplicity of the dynamic stability of current transformer (see note by 5 to Table P-17).

The thermal resistance of current transformer they characterize by referred to certain time multiplicity of the thermal resistance, equal to the ratio of the current of thermal resistance for to preset time t to primary the rated current of current transformer:

$$K_t = \frac{I_t}{I_{1ном}}.$$

Being guided by general condition (21-5) for the thermal

resistance of apparatuses, we can write the following condition for the thermal resistance of current transformer:

$$(K_t I_{1ном})^2 t \geq I_{\infty}^2 t_ф. \qquad (21\text{-}17)$$

In the majority of the cases the multiplicity of the thermal resistance of current transformers is given referred to time t=1 s.

The primary winding of busbar/tire current transformer is the busbar of distributor which is checked against thermal resistance when selecting of the busbars of the corresponding circuit. Therefore the multiplicity of the thermal resistance of busbar/tire current transformer characterizes the thermal resistance of its secondary winding.

Voltage transformers select on: 1) to the nominal voltage; 2) to the kind of the installation; 3) the construction/design; 4) to the class of the precision; 5) to burden.

They preliminarily compose the trilinear circuit diagram of instruments and relay which will be supplied from voltage transformer. Depending on type and designation/purpose of instruments they install, in what class of precision must work voltage transformer.

Then, being guided by conditions 1-4, is selected through

catalog the type of voltage transformer and they find its nominal power $S_{2ном}$ in the class of precision (Table P-18) accepted.

After selecting through catalogs the types of measuring meters and relay, they find, what power $S_{приб}$ (VA) consume their parallel coils and are such their factors of power $\cos\varphi_{приб}$. Then determine the total load of voltage transformer or group of single-phases transformer the voltages:

$$S_2 = \sqrt{(\Sigma P_{приб})^2 + (\Sigma Q_{приб})^2}, \quad (21\text{-}18)$$

where

$$\Sigma P_{приб} = \Sigma(S_{приб} \cos\varphi_{приб})$$

and

$$\Sigma Q_{приб} = \Sigma(S_{приб} \sin\varphi_{приб})$$

- total with respect active and reactive power, consumed by all parallel coils of instruments and relay.

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Obtained burden must not exceed the nominal power of transformer of voltage in the class of precision accepted, i.e.,

$$S_{ном} \geqslant S_2. \quad (21\text{-}19)$$

If voltage transformer supplies the receivers of electric power for which does not have a value magnitude of error, then are observed the condition:

$$S_{макс} \geqslant S_2, \quad (21\text{-}20)$$

where $S_{макс}$ - the maximum permissible power of voltage transformer.

In the case of the group of single-phases transformer of voltage by $S_{ном}$ and $S_{макс}$ it is necessary to understand the total power of the transformers of group.

Since the phases of voltage transformer can be loaded differently, then more precise is the determination of the load of one phase and its comparison with the nominal power of one phase of voltage transformer in the class of precision [13-1] accepted.

Section of strands of wires and cables, connecting the transformers of voltage with measuring meters, one should select from the condition so that the loss of voltage in circuit from voltage transformer to instruments would not exceed 3o/o of nominal voltage, and in the presence of calculated counter - not more than 0.5o/o, in this case according to the condition of mechanical strength section of strands of wires and cables must be not less: copper 1.5 mm^2, aluminum 2.5 mm^2 [3-6 and 19-2].

Voltage transformers and established/installed in their circuit electrical equipment to the action of short-circuit currents do not

check.

21-4. Example 21-1. Selection of electrical apparatuses.

At the station whose diagram is given in Fig. 21-1, to select and to check to stability during the short circuit: switch and disconnector of generator, switch, disconnectors and current transformers in the circuit of the waste/exiting cable line 10 kV and voltage transformer in the first section of the collecting mains of station.

Station works in parallel with power system. Inductive reactance of system to the busbars 110 kV of station, in reference to the nominal power of system $S_{c.ном} = 600$ MVA, comprises $x_{*c} = 0,7$.

The turbogenerators of station G-1 and G-2: $S_{г.ном} = 31.24$ MVA $x''_{*d} = 0,132$, $U_{г.ном} = 10,5$ kV, are equipped ARV.

Raising transformers T-2 and T-3: $S_{т.ном} = 20$ MVA, $u_к = 10,5\%$. are normally connected both transformers.

From each section of the collecting mains of station they will move away eight lines with normal load 3 MVA each. Under emergency conditions the maximum constant load of lines is 6 MVA.

For the feed of their own needs are established/installed three transformers.

As it is dismantled/selected into §21-2, the calculation point of short circuit for the selection of electrical equipment of generator is point K-1, and for the selection of electrical equipment of the waste/exiting line - a point K-9.

Values of short-circuit current, which flows into point K-1:

$$I''^{(3)} = I''^{(3)}_{г\cdot 2} + I''^{(3)}_{c} = 13 + 14{,}5 = 27{,}5 \text{ ка};$$

$$i_y^{(3)} = 1{,}9 \cdot \sqrt{2} \cdot 13 + 1{,}8 \cdot \sqrt{2} \cdot 14{,}5 \approx 72 \text{ ка};$$

$$S''^{(3)} = 500 \text{ Мва}; \; I_\infty^{(3)} = 20 \text{ ка}; \; I_\infty^{(2)} = 19{,}5 \text{ ка}.$$

Key: (1). kA.

Values of short-circuit current, which flows into point K-9 from G-1, G-2 and system $I_к = I''^{(3)} = I_\infty^{(3)} = 8{,}4$ kA; $i_y^{(3)} = 22$ kA; $S_к = S'' = 153$ MVA.

Fundamental relaying of generator is the differential protection the time of action of which let us take as equal to 0.1 s. The waste/exiting cable lines are equipped with the protection of the maximum current in the course of time of action, equal to 2 s.

On generators and waste/exiting lines we intend to establish/install oil breakers with small space of oils the tripping time of which let us accept $t_{n}=0.2$ s.

Let us assume that on each waste/exiting line are established/installed one ammeter and counter, and also relaying of maximum current in two phases, performed by electromagnetic overload relays. On the side 10 kV of each transformer of its own needs are established/installed the ammeter, wattmeter and counter.

In each section of collecting mains are established/installed arrow and that records voltmeters for the control/checking of voltage on busbars, arrow and that records frequency meters for the inspection of frequency and three voltmeters for the inspection of insulation state.

The column of synchronization consists of synchroscope, two voltmeters and two frequency meters.

Voltage transformer, established/installed in the section of collecting mains, is intended for the feed of the parallel coils of the measuring meters of collecting mains, waste/exiting lines and transformers of its own needs. From it are supplied the instruments of synchronization with the synchronization of generator of

collecting mains.

Entire electrical equipment of generator voltage is placed in the closed distributor, with respect to what it must be selected for internal installation.

Apparatuses in the circuit of generator. The greatest let-go current of generator is determined when the voltage of the generator is lowered/reduced by 5o/o:

$$I_{п.макс} = \frac{31\,250}{\sqrt{3}\cdot 10} = 1\,800\ a.$$

Generator switch (V-1). Duration of the course of current $t = t_{защ} + t_в = 0{,}1 + 0{,}2 = 0{,}3$ s.

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Since $I_\infty^{(3)} > I_\infty^{(2)}$, then in thermal sense is more dangerous the current of three-phase short circuit. We determine the fictitious time taking into account aperiodic component/term of short-circuit current, since t<1 s.

On curves in Fig. 7-6 when β'' -27.5/20=1/37 and t=0.3 s we find $t_{ф.п} = 0{,}4$ s. According to formula (7-12) $t_{ф.а} = T_а \beta''^2$ =0.05•1.37²=~0.09 s. Then $t_ф = 0{,}4 + 0{,}09 \approx 0{,}5$ s.

In the following table we extract all calculation data, necessary for the selection of switch. Being guided by these data and using Table P-14, we select an oil breaker of the type MGG-10, the parameters which we enter in the same table. Comparison calculated values with the parameters of switch shows that all necessary conditions are satisfied and switch is selected correctly.

(1) Расчетные данные		(2) Параметры выключателя типа МГГ-10	
$U_{уст.\,ном}$	10 *кв*	$U_{ном}$	10 *кв* (3)
$I_{н.\,макс}$	1,8 *ка*	$I_{ном}$	2 *ка* (4)
I''	27,5 *ка*	$I_{отк.\,ном}$	29 *ка* (4)
S''	500 *Мва*	$S_{отк.\,ном}$	503 *Мва* (5)
i_y	72 *ка*	$i_{макс}$	75 *ка* (4)
$I_\infty^2 t_\Phi$	$20^2 \cdot 0{,}5 = 200$ *ка²·сек* (6)	$I_{10\,сек}^2 10$	$21^2 \cdot 10 = 4\,410$ *ка²·сек* (6)

Key: (1). Calculation data. (2). Parameters of switch of type MGG-10. (3). kV. (4). kA. (5). MVA. (6). kA²•s.

For control of switch we select electromagnetic actuator of the type PE-2 (tables P-14 and P-16).

The disconnector of generator (R-1) must be selected according to the same calculation data, as switch, eliminating condition for the selecting according to the disconnecting ability. On Table P-13 we select tripolar disconnector for internal installations of the type RLV-III-10/2000 whose parameters, as is evident from the forthcoming table, they completely correspond to design conditions.

(1) Расчетные данные		(2) Параметры разъеднителя типа РЛВ-III-10/2000	
$U_{уст.\,ном}$	10 кв	$U_{ном}$	10 кв (3)
$I_{н.\,макс}$	1,8 ка	$I_{ном}$	2 ка (4)
i_y	72 ка	$i_{макс}$	86,5 ка
$I_{\infty}^2 t_ф$	$20^2 \cdot 0{,}5 = 200$ ка²·сек (5)	$I_{10\,сек}^2 10$	$36^2 \cdot 10 = 13\,000$ ка²сек (5)

Key: (1). Calculation data. (2). Parameters of disconnector of type. (3). kV. (4). kA. (5). kA²•s.

For control of disconnector we select manual rigging of the type PR-31.

Apparatuses in the circuit of the waste/exiting cable line 10 kV. Maximum prolonged current of the load of the line

$$I_{н.макс} = \frac{6\,000}{\sqrt{3} \cdot 10} = 346\ a.$$

Switch of line (V-6). Duration of the course of short-circuit current t=2+0.2=2.2 s. Since the point of short circuit K-9 distant, then $t_ф = t = 2{,}2$ s (aperiodic component/term we do not consider).

We extract into table calculation data and on Table P-14 we select the type of switch. From oil breakers with small space of oil most corresponds to design conditions the switch of the type VMG-133-I whose parameters we compare in the same table with calculation data.

(1) Расчетные данные		(2) Параметры выключателя типа ВМГ-133-I	
$U_{уст. ном}$	10 *кв* (3)	$U_{ном}$	10 *кв* (3)
$I_{н. макс}$	346 *а* (4)	$I_{ном}$	600 *а* (4)
$I_{к}$	8,4 *ка* (5)	$I_{отк. ном}$	11,6 *ка* (5)
$S_{к}$	153 *Мва* (6)	$S_{отк. ном}$	200 *Мва* (6)
i_{y}	22 *ка* (5)	$i_{макс}$	52 *ка* (5)
$I_{к}^{2} t_{ф}$	$8{,}4^2 \cdot 2{,}2 \approx 155$ *ка²·сек* (7)	$I_{10\,сек}^{2} 10$	$14^2 \cdot 10 = 2\,000$ *ка²·сек* (7)

Key: (1). Calculation data. (2). Parameters of switch of type. (3). kV. (4). A. (5). kA. (6). MVA. (7). kA²•s.

For control of switch we select electromagnetic actuator of the type PS-10.

The busbar/tire (RSh) and linear (RL) disconnectors of line must satisfy the same design conditions as the switch of line. On Table P-13 we select tripolar disconnectors busbar/tire of the type RV-10/400 and linear of the type RVZ-10/400 (with the grounding knives), the parameters which we enter in design schedule. All parameters of disconnectors satisfy design conditions.

(1) Расчетные данные		(2) Параметры разъединителей типов РВ-10/400 и РВЗ-10/400	
$U_{уст. ном}$	10 *кв* (3)	$U_{ном}$	10 *кв* (3)
$I_{н. макс}$	346 *а* (4)	$I_{ном}$	400 *а* (4)
i_{y}	22 *ка* (5)	$i_{макс}$	50 *ка* (5)
$I_{\infty}^{2} t_{ф}$	$8{,}4^2 \cdot 2{,}2 \approx 155$ *ка²·сек* (6)	$I_{10\,сек}^{2} 10$	$10^2 \cdot 10 = 1\,000$ *ка²·сек* (6)

Key: (1). Calculation data. (2). Parameters of disconnectors of types RV1/400 and RVZ-10/400. (3). kV. (4). A. (5). KA. (6). kA²•s.

For control of disconnectors we select manual lever drives of the type PR-2.

Current transformers. The design conditions the same as for the selection of the switch of line.

Current transformers we install in two phases A and C. The circuit diagram of measuring meters and relay is given in Fig. 21-2. Current transformers we select with two cores for the purpose of the independence of the circuits of instruments and relaying.

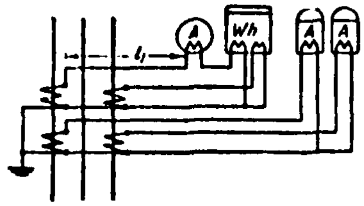

Fig. 21-2. Schematic of the connection of instruments and relay to current transformers, connected into incomplete star.

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Counters on the waste/exiting lines of generator voltage belong to the group of calculations (§19-1); therefore must be connected up them the core coils of current transformers, which work in the class of precision 0.5. Relaying of maximum current can be supplied from windings of cores, which work in the class of precision 3 (supposedly).

Being guided by these conditions, and also knowing the nominal voltage of installation and the current of the peak load of line, on appendix P-17 we plan the type of current transformer. Adequate/approaching is passage multiturn current transformer of the type TPF10-0.5/3-400 on 400 A and 10 kV with porcelain insulation and two cores. Nominal secondary power of the core of class 0.5 $S_{2\,ном}=15$ VA, and the core of class 3 $S_{2\,ном}=30$ VA.

Power, consumed by consecutive by the coils of measuring meters (Table P-19):

(1) Наименование прибора	(2) Тип	(3) Нагрузка, ва	
		(4) фаза A	(4) фаза C
(5) Амперметр электромагнитный	ЭА-2	1,73	—
(6) Счетчик трехфазный индукционный	ИТ	0,525	0,525
(7) Итого		2,255	0,525

Key: (1). Designation of instrument. (2). Type. (3). Load, VA. (4). phase. (5). Ammeter (electromagnetic). (6). Counter three-phase induction. (7). Altogether.

Is most loaded current transformer of phase A. We determine the power which can be lost in coupling cable from current transformers to the measuring meters (counting for the consecutive coils of instruments $\cos\phi=1$), accepting $I_{2\,ном}=5a$ and $r_{конт}=0{,}1$ ohm:

$$S_{пров}=S_{2\,ном}-(\Sigma S_{приб}+I^2_{2\,ном}r_{конт})=$$
$$=15-(2{,}255+5^2\cdot 0{,}1)\approx 10{,}24\ ва.\ (1)$$

Key: (1). VA.

Permissible resistor/resistance of the wires

$$r_{пров}=\frac{S_{пров}}{I^2_{2\,ном}}=\frac{10{,}24}{25}=0{,}41\ ом.\ (1)$$

Key: (1). ohm.

We assume that the measuring meters and relay will be established/installed in the corridor of the control of distributor on the wall of the corresponding cell. Then the length of the connecting drive from transformer of current to measuring meters is approximately/exemplarily 4 m (one-way trip). With the connection of current transformers into incomplete star the section of jumpers must be not less:

$$s = \frac{\sqrt{3}\, l_1}{\gamma r_{\text{пров}}} = \frac{\sqrt{3} \cdot 4}{53 \cdot 0{,}41} \approx 0{,}32 \text{ мм}^2.$$

According to the condition of mechanical strength should be accepted the section of wires 2.5 mm².

The transformer core of current for relaying is selected during development by the latter.

Let us accept the distance between the busbars of different phases a=400 mm and distance from the cap/hood of the insulator of current transformer to nearest supporting/reference insulation l =600. Then the effort/force, which operates on the cap/hood of the insulator of current transformer, according to formula (21-16) comprises:

$$F_{\text{расч}} = 0{,}5 \cdot 1{,}76 \cdot 22^2 \frac{60}{40} \cdot 10^{-2} \approx 6 \overset{(1)}{\text{кГ}}.$$

Key: (1). kgf.

In the following table we compare calculation data with the parameters of current transformer.

(1) Расчетные данные		(2) Параметры трансформатора тока типа ТПФ10-0,5/3-400	
$U_{\text{уст. ном}}$	10 *кв* (3)	$U_{\text{ном}}$	10 *кв* (3)
$I_{\text{н. макс}}$	346 *а* (4)	$I_{\text{ном}}$	400 *а* (4)
i_y	22 *ка* (5)	$K_{\text{дин}}\sqrt{2}I_{1\ \text{ном}}$	$165\sqrt{2}\cdot 0{,}4\approx 93$ *ка* (5)
$I_{\text{к}}^2 t_{\Phi}$	$8{,}4^2\cdot 2{,}2\approx$ ≈ 155 *ка²·сек* (6)	$(K_t I_{1\ \text{ном}})^2 t$	$(75\cdot 0{,}4)^2\cdot 1=$ $=900$ *ка²·сек* (6)
$F_{\text{расч}}$	6 *кГ* (7)	$F_{\text{доп}}$	150 и 75 *кГ* (7)

Key: (1). Calculation data. (2). Parameters of current transformer type. (3). kV. (4). A. (5). kA. (6). kA²•S. (7). kgf.

Voltage transformer on collecting mains. Since voltage transformer is intended for the feed of the parallel coils of measuring meters and for the inspection of insulation state, then we select three-phase five-rod voltage transformer of the type NTMI-10 on primary voltage 10 kV and secondary voltage 100 V (Table P-18). To voltage transformer are connected the counters; therefore it must work in class 0.5. Permissible load in this class $S_{\text{ном}}=120$ VA. The schematic diagram of the connection of the parallel coils of instruments to voltage transformer is shown in Fig. 21-3.

Burden we determine in the following table (instruments of synchronization we do not consider).

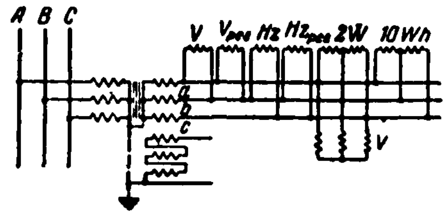

Fig. 21-3. Schematic of the connection of the parallel winding of measuring meters to five-rod voltage transformer.

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Full load on voltage transformer will comprise:

$$S_2 = \sqrt{P^2+Q^2} = \sqrt{85,8^2+32,4^2} \approx 92 \overset{(1)}{\text{ва}}.$$

Key: (1). VA.

Since $S_2 < S_{ном}$, then voltage transformer will work in the selected class of precision 0.5.

For the protection of voltage transformer from short circuits we install from the side of voltage 10 kV safety fuses of the type PKT-10. These safety devices/fuses are current-limiting and possess the limiting current of cutoff/disconnection 50 kA (Table P-12). Since ultratransitory short-circuit current on collecting mains (during closing/shorting in K-3) composes I'' =26+14.5=40.5 kA, then they possess the sufficient disconnecting ability.

According to the condition of mechanical strength the section of copper strands of coupling cable from voltage transformer to instruments must be not less than 1.5 mm^2. For checking the cable to the loss of voltage it is necessary to have available the assembly diagram of the start of instruments to voltage transformer.

(1) Наименование прибора	(2) Тип	(3) Потребляемая мощность параллельной катушкой, *ва*	(4) Число катушек	cos φ	sin φ	(5) Число приборов	(6) Потребляемая мощность катушками всех приборов (7) *P, вт*	(8) *Q, вар*
(9) Вольтметр электромагнитный	ЭВ-2	7,2	1	1	0	4	28,8	0
(10) Ваттметр активный трехфазный	ФДВА-2	1,8	2	1	0	2	7,2	0
(11) Счетчик	ИТ	1,75	2	0,38	0,925	10	13,3	32,4
(12) Частотомер	Д340	6,5	1	1	0	1	6,5	0
(13) Вольтметр регистрирующий	Д33	15	1	1	0	1	15	0
(14) Частотомер регистрирующий	Н305	15	1	1	0	1	15	—
(15) Итого. . . .	—	—	—	—	—	—	85,8	32,4

Key: (1). Designation of instrument. (2). Type. (3). Required power by parallel coil, VA. (4). Number of coils. (5). Number of instruments. (6). Consumed coil power of all instruments. (7). W. (8). pitch/var. (9). Voltmeter (electromagnetic. (10). Wattmeter active three-phase. (11). Counter. (12). Frequency meter. (13). Voltmeter, which records. (14). frequency meter, recording. (15). Altogether.

Chapter twenty-two.

ALTERNATORS AND COMPENSATORS.

22-1. Types and fundamental characteristics.

Depending on the kind of primary engine are distinguished two fundamental types of alternators: turbogenerators and hydraulic generators. Turbogenerators are intended for direct connection with steam turbines, and hydraulic generators - with hydraulic turbines.

The general view of turbogenerator is shown in Fig. 22-3. With an increase in the rotational speed the sizes/dimensions and the weight of turbines and generators decrease, which gives the series/row of economic advantages. Therefore Soviet plants manufacture predominantly two-pole turbogenerators on 3000 r/min, what is the maximum possible speed of rotation of alternator at current frequency 50 Hz.

The rotors of turbogenerators perform cylindrical form with the implicitly expressed poles (without salient poles) and the diameter not more than 1-1.1 m. Is explained this by the fact that at the large rotational speed the external parts of the rotor are located

under the action of very considerable centrifugal forces, that it does not make it possible to reliably fasten on rotor salient poles and excitation winding. In cylindrical steel forged rotor of turbogenerator are milled out longitudinal slots, into which place the conductors of the rotor winding, which is the winding of excitation of generator. The slots/grooves of rotor are closed with metallic keys, but end connections of the rotor winding, which do not lie at slots/grooves, secure by the durable steel bindings (caps), preventing the deformation of end connections of the rotor winding under the action of centrifugal forces.

In hydroelectric stations the speed of rotation of hydroturbines usually lies/rests within the limits of 60-750 r/min and is determined by the value of the hydraulic head, by power and construction/design of hydroturbine itself and a series/row of other conditions.

In accordance with natural conditions on large/coarse Soviet hydroelectric plants are established/installed mainly the aggregates/units in rotational speed from 62.5 to 125 r/min.

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As a result of a comparatively small speed the rotations the rotors

of hydraulic generators make to a large number of clearly expressed poles. For example, with n=62.5 r/min and f=50 Hz the rotor of hydraulic generator has p=50•60/62.5=48 pairs or 96 poles. The diameters of such rotors are great and reach 8-10 m (with diameter more than 4 m rotors make with dismountable ones).

Hydroaggregates usually have vertical fulfillment during the location of hydraulic generator in the upper part of the aggregate/unit, in machine room, as is evident in Fig. 2-9. The hydraulic generators of small and average/mean power if necessary are fulfilled with side shaft.

The hydraulic generators of average and large power usually have on rotor the damping (damping) windings, made by the copper rods, packed in polar extremities and by short-circuited copper bands on ends/faces poles.

Normally rotor and magnetic flux of the stator of polyphase alternator rotate synchronously; therefore in the damper windings of the rotor of no current it is induced. In the case of changing the steady mode/conditions of the work of generator (increase or decrease of load, short circuit in network/grid, etc.) the rate of the rotation of rotor is disrupted and it completes some oscillations/vibrations of the relatively rotating field of stator.

This in turn, produces change in the magnetic flux, engaged with the damper windings of the poles of rotor, and the induction in them of currents. Interaction of the latter with the magnetic flux of stator will brake (it damps) the oscillations/vibrations of rotor, seemingly it attenuates these oscillations/vibrations.

In turbogenerators, machines from cylindrical rotor, damper windings they do not obtain satisfaction, since their role perform metallic keys, the fastening conductors of excitation winding in slots/grooves, and the steel body (flank) of rotor. The elements/cells indicated, which perform the role of damper windings, is conventionally designated as the damping outlines of the turbogenerators [for greater detail, see 6-2].

The fundamental technical characteristics of turbo- and hydraulic generators of Soviet plants are given in Tables P-1 and P-2.

For connection with diesels apply multipole generators with side shaft at speed the rotations 750-1000 r/min.

The synchronous condensers are applied in the electric systems of power systems as the supplementary to generators power plants of the sources of the reactive power, necessary for the work of power

consumers and electrical network. The synchronous condenser is the synchronous electric motor, which does not carry mechanical load. With work with overexcitation the synchronous condenser gives up in network/grid the reactive power [for greater detail, see 6-2 and 7-1].

The speed of rotation of the synchronous condensers is usually 600-1000 r/min; therefore their rotors are performed with the clearly expressed poles. On the latter there are damper windings, calculated as starting windings, which create the necessary starting/launching torque during the asynchronous launching/starting of the synchronous condenser (see §22-7).

Everything presented below, if there are no special indications, in equal measure is related both to alternators and to the synchronous condensers.

The nominal values, which characterize synchronous machine, are: nominal voltage, nominal power the rated current of stator, the rated current of excitation (rotor), the nominal coefficient of power and nominal frequency. All these values are indicated in the plant certified/rating table of machine.

The nominal voltages of synchronous machines were shown earlier

in §3-1 (see also Tables P-1, P-2 and P-3).

Nominal frequency in the USSR is accepted by 50 Hz.

The nominal power of synchronous machines is defined as the long permissible load of machine in kilo-volt-amperes at a specific calculated temperature of the cooling gas (air or hydrogen) and long permissible temperature of heating winding and steel of stator and rotor winding. For three-phase machines $S_{\text{ном}}=\sqrt{3}U_{\text{ном}}I_{\text{ном}}$.

The nominal power of the synchronous condenser is determined analogously, but with the anticipating/leading current, i.e., when the synchronous condenser works with overexcitation with the anticipating/leading current, equal to the rated current of stator, and with nominal load voltage of stator.

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The long permissible temperatures of heating windings of steel different for different types machines they depend on the kind of used insulation. Precise values of these temperatures with long running of machine with nominal load with nominal power factor are established/installed according to the results of running tests for heating and they are indicated in station-type instructions. In the

majority of the cases they do not exceed 100-120°C for the windings of stators and 105-145°C for the rotor windings. The temperature of steel in the location of winding must not be the more than permissible temperature for the latter. In this case it is assumed that the temperatures of heating windings and steel of stator measure with the thermo-detectors (see Vol. 2, chapter 15), placed between the rods of windings and to the bottom of the slots/grooves of stator, but the temperature of heating the rotor windings determine by method changes in the resistor/resistance during heating.

The insulation of machines gradually is abraded (it ages) as a result of the effect on it of electric field, under the action of different mechanical loads (vibration of machines, electrodynamic action of short-circuit currents, friction of the jet of the cooling gas, etc.), as a result of its contamination, moistening, atmospheric oxidation and series/row of other reasons. Especially great effect on ageing of insulation exerts its heating: the higher the temperature of heating insulation, the more rapid it is abraded, the less its service life. For example, if we take that most widely used for the windings of stator-rotors unit the insulation, made from mica, asbestos or other mineral materials with binders on varnish (insulation of class C), then during heating to temperature of 120°C service life of its is approximately 15 years, and during heating to 140°C service life of its sharply decreases, almost of up to 2 years.

The considerable heating of insulation leads to the decrease of its elasticity, it becomes brittle, its dielectric strength sharply decreases. The same insulation at a temperature of heating on the order of 105°C ages slowly and the period of its service becomes more than 25-30 years.

Therefore in operation during any modes/conditions of the work of machine it is not possible to allow/assume heating its insulation more than established/installed for it maximum permissible temperatures.

Synchronous machines are cooled by air or hydrogen (gas). The nominal temperature of the entering the machine cooling gas is called its that calculated temperature with which the machine can how conveniently long work with nominal power.

Soviet plants manufacture the synchronous machines, designed for the efficiency of nominal power at following nominal temperatures of the entering in them gas: turbogenerators of +40°C (up to 1941 was accepted temperature of +35°C); the hydraulic generators and all other generators, intended for connection with diesels, engines, etc., +35°C; synchronous condensers of +40°C (up to 1956 - +35°C).

If the temperature of the entering the machine cooling gas

higher than nominal (40° or 35°C), then the conditions for its cooling deteriorate also for retaining/preserving/maintaining the service life of machine the let-go currents of stator-rotor unit must be reduced so so that the temperatures of heating windings would not exceed nominal value. On the contrary, if the temperature of the entering the machine cooling gas lower than nominal, then cooling machine is improved also without the decrease of the period of its service the armature currents and rotor can be somewhat increased to the values, with which the temperatures of their heating will be equal to nominal. The corresponding permissible values of the armature currents and rotor at different temperatures of the cooling gas, different from nominal, set to the data of running tests of machines for the heating [see also 22-1].

Prolonged overloadings over the currents, permitted at this temperature of the entering the machine cooling gas, are not allowed/assumed. The permissible under emergency conditions short-term overloadings are established by station-type instructions.

Let us note that the temperature of the emerging from machine cooling gas is not calibrated. In operation it is necessary to follow overheating of the cooling gas in machine, i.e., after difference $\vartheta_{вых} - \vartheta_{вход}$. Usually overheating composes approximately/exemplarily 20-30°C. An increase in the temperature of overheating gas in machine

at normal temperature of the entering gas indicates any malfunction of machine or system of its cooling.

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The rated current of rotor consider that maximum current the excitations of machine, with which is provided the efficiency by the machine of its nominal power in kilo-volt-amperes with voltage error on the terminals/grippers of stator within limits of +-5o/o of nominal value and when the generator works with nominal power factor, and the synchronous condenser - with the anticipating/leading current [3-2, 22-1 and 22-2]. Hence it follows that the synchronous machines can be loaded to nominal power with voltage error on the terminals/grippers of stator within limits of +-5o/o. Respectively greatest let-go current of the stator

$$I_{\text{н.макс}} = \frac{S_{\text{ном}}}{\sqrt{3}\cdot 0{,}95\, U_{\text{ном}}} = 1{,}05\, I_{\text{ном}}.$$

With voltage it is less than 0.95 $U_{\text{ном}}$ prolonged armature current must not exceed the greatest value indicated. Respectively the load of machine in kilo-volt-amperes it is necessary to decrease. So, with voltage 0.8 $U_{\text{ном}}$ machine can be loaded on $S = \sqrt{3}\cdot 0{,}8\, U_{\text{ном}}\, 1{,}05\, I_{\text{ном}} = 0{,}84\, S_{\text{ном}}$, to 84o/o of nominal power.

Generators and synchronous condensers can work with the voltage, which exceeds nominal by 10o/o. However, since the current of rotor

cannot be more than nominal, the voltage 1.1 $U_{ном}$ on the terminals/grippers of machine it can be obtained only by corresponding reduction in current of stator, i.e., the load of machine [22-2].

With the unsymmetrical loading of phases on the stator of machine is created the fluctuating magnetic flux which, as is known, it can be decomposed on two rotating magnetic fluxes: the flow of forward sequence, which rotates synchronously with rotor, and the flow of backward sequence, which rotates with the synchronous speed to opposite side.

The flow of forward sequence is the flow of the reaction of stator.

The flow of backward sequence rotates relative to rotor with the dual synchronous speed and induces the currents of dual frequency in excitation winding and in the steel body of rotor (Fig. 22-1). These currents cause additional coil losses of excitation and in the metallic parts of the rotor and heat them.

If on rotor are damper windings, which possess low effective resistance, then the magnetic flux of backward sequence induces in them the considerable in value currents of the dual frequency (as in

secondary quadrature winding of transformer). These currents in damper windings create their magnetic flux which to a considerable degree compensates the magnetic flux of backward sequence of stator.

As a result of this sharply descend the strengths of currents of the dual frequency which are induced in excitation winding and in the steel body of rotor and, consequently, also their supplemental heat.

The greatest supplemental heat with the unsymmetrical loading of phases is observed in turbogenerators, since they do not have damper windings, but the conductors of the rotor winding in them are located in closed slots that impedes their cooling. Especially strongly are heated the body of rotor and its bindings.

In the best position are located the machines with the clearly expressed poles, since their excitation winding is cooled considerably better. Favorable is the fact that many machines with the clearly expressed poles, especially average/mean and large power, have damper windings.

Besides that indicated above with the unsymmetrical loading of phases is disrupted the equilibrium of forces of interaction between the poles of rotor and the stator of machine, as a result of which appear the vibration of dual frequency and additional mechanical

stresses in some machine parts. For machines with the clearly expressed poles the permissible asymmetry of the load of phases is usually determined precisely from the conditions of the onset of these vibrations.

Taking into account that presented, in operation with the full load of machines allow/assume work with the inequality of currents in phases not more than 10o/o nominal armature current for turbogenerators and 20o/o - for hydraulic generators and synchronous condensers. In this case not in one of the phases the current must not be more than nominal. With smaller loads it is possible to allow the large nonuniformity of current in phases, determined by the tests of machine [3-2, 22-1 and 22-3].

As noted into chapter 5, generators and synchronous condensers in networks/grids with the ungrounded neutrals and in the compensated networks/grids can continue to work during single-phase closing/shorting to the earth in network/grid, but are not more than 2 h. In this case the current of single-phase closing/shorting to the earth must not exceed 30 A [3-5 and 22-1].

The nominal factor of the power of the majority of alternators is equal to 0.8 and only in powerful/thick turbogenerators it is equal to 0.85-0.9 (Tables P-1 and P-2).

From the value of the power factor, with which works the generator, depends the value of the field current of generator. With the same load of generator in kilo-volt-amperes the less the power factor, the greater the field current, the greater charging rotor.

The work of generator with the factor of the power of less than the nominal leads to the incomplete use of power of aggregate/unit.

Let us take for an example the turbogenerator with a power of 15 MVA when $\cos\varphi_{\text{ном}}=0.8$, connected with turbine in power of 15•0.1=12 MW.

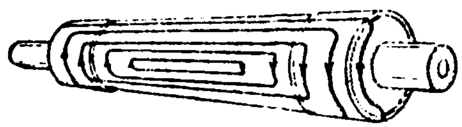

Fig. 22-1. Track layout of passage in the rotor of the turbogenerator of the currents, induced by the magnetic field of reverse sequence.

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Let us assume that the generator works from cosϕ=0.6. With decrease in the power factor the field current of generator must be increased. However, the prolonged overloading of the rotor winding is not admitted, and for maintaining normal load voltage of generator with cosϕ=0.6 it is necessary to lower the load of generator approximately/exemplarily to 14o/o (according to the data of plant "electric power"). As a result of this the load of generator must be limited by the power of 15•0.86=12.9 MVA (underloading 14o/o). The load of turbine will be 12.9x0.6=7.74 MW (underloading of approximately 35.5o/o).

22-2. Cooling systems.

During the work of synchronous machine windings and steel of stator-rotor unit are heated. So that the temperature of heating

machine parts would not exceed the permissible values, is necessary their permanent cooling. Good heat removal provides the lower temperatures of heating insulation, which increases the service life of machine and makes it possible in certain cases to increase the let-go currents of stator-rotor unit of machine.

Synchronous machines can be cooled by gas - air, hydrogen, or liquid - oil, water.

Is most common ventilation of the synchronous machines: all small synchronous machines, turbogenerators in power to 15 MW inclusively and the hydraulic generators of all power are fulfilled only with ventilation.

Hydrogen cooling is used in the following machines of domestic manufacture: in turbogenerators on 3000 r/min with a power of 25-30 MW and more (issue after 1950) and in the synchronous condensers in power 37.5 and 75 MVA.

During air and hydrogen cooling the cooling gas drives away itself through the machine by the fans, established/installed from the ends/faces of rotor.

Subsequently it is assumed to use the liquid cooling of

synchronous machines, also, first of all of the projected/designed very large/coarse turbogenerators with a power of 300 MW and more.

Ventilation. There are two systems of ventilation of the machines: flowing (extended) and locked.

With flowing ventilation cold air enters machine outside and, in passing by through it, it is rejected into machine room or outside. In this case is necessary careful dusting of the entering the machine air. The contamination of air ducts and windings of machine makes cooling worse and it leads to an increase in the temperature of heating its parts. Possibly also the disconnection of the insulation of windings.

However, even cleaning/purification of air coolant in special filters (fabric or oil) turn out to be insufficient and is observed certain contamination of machine; therefore this cooling system is applied only for the machines of comparatively small power. So, on the in force standards with flowing ventilation can be manufactured turbogenerators in power to 1.5 MW inclusively (GOST [All-union State Standard] 533-51), hydraulic generators to 4 MW (GOST 5616-50) and synchronous condensers to 5 MVA, and sometimes and to 15 MVA (GOST 609-54). The machines of large power are performed with locked ventilation.

With locked ventilation through the machine continuously drives away itself always one and the same volume of air (Fig. 22-2). The emerging from machine hot air passes through water air cooler 1 and, after being cooled, again it enters machine. In air cooler the cooling water flows/occurs/lasts over tubes, in the gaps/intervals between which is passed the air-cooled.

The air coolers of turbogenerators and synchronous condensers usually install under machine in the chamber/camera of cooling air as this shown in Fig. 22-2. In large/coarse hydraulic generators with vertical shaft the air coolers normally place around the stator of generator.

In cold season the temperature of the entering the machine air must not be lower than specific value, established experimentally, to avoid the sweating of separate machine parts. Must not be also sweating of air cooler to avoid drift into the machine of the drops of water and corrosion of air cooler, as a result of which decreases its cooling capacity. For removing condensed on air cooler water, and also in the case of its leak in the chamber/camera of cold air they perform containers 3 (Fig. 22-2), from which the water along tube 4, equipped with hydraulic gate 5, is abstracted/removed into the catch

drain (in figure it is not shown).

Pressure in different parts of the cooling system is different. So, in the regions, noted by letter B, pressure are somewhat increased, in consequence of which through the leakages/loosenesses of this part of the cooling system occurs certain air leakage.

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On the contrary, in the chamber/camera of cold air G, and especially in A fields, whence the fans of machine draw-in air, is created certain rarefaction/evacuation due to which through the leakages/loosenesses of this part of the cooling system it can occur a certain air suction. The small, but permanent aspiration of external air considerably contaminates machine. For elimination of this is necessary good multiplexing of cooling system. Furthermore, in the chamber/camera of cold air G are installed dual oil filters 2, through which is sucked the air from condensation location how are completed its losses through escapes.

Oil filters consist of separate rectangular cases (cells) whose two opposite walls are made from the gratings, filled with the short cuts of steel tubes (rings), moistened in viscin oil (by inserting in it the case with the filler indicated). Viscin oil is characterized

by large viscosity and gumminess; therefore with the passage of air in the gaps/intervals between the filler the large part of the containing in it dust adheres to oil (filter delays to 85o/o of dust). Intermittent filters they clean from the accumulated dust and again charge.

Must not be air suction into the cooling system of machine and through its leakages/loosenesses - through the joints between housing and panels, between panels and shaft, between housing and bed. This is achieved by creation in the region of these joints of the elevated pressure under action of which the air through joint leakage can only emerge outside.

Fig. 22-2 schematically shows a similar system of the creation of labyrinth packing in contemporary turbogenerators with ventilation of Soviet plants [22-2]. With the aid of special chambers/cameras D, which have the form of grooves, the air of plenums B is fed/conducted to all joints indicated above and through them leaks in the atmosphere. Chamber/camera D is peculiar buffer which does not allow/assume air suction inside machine. Is eliminated also the possibility of inflow along shaft into the turbogenerator of the particles of oil from bearings, which greatly detrimentally operates on the insulation of the windings of machine.

The advantages of closed-cycle cooling system consist in the absence of bulky filters, small contamination of machine and ease/lightness of the liquidation of fire as a result of the absence of flow of air from without.

Quenching of fire in machines with ventilation. Fire in machine can arise during its different damages, which are especially accompanied by the onset of electric arc in the place of damage (interphase short circuits, single-phase contacts to frame vault). The rapid liquidation of fire decreases the sizes/dimensions of the damage of generator. Therefore all hydraulic generators, turbogenerators and synchronous condensers with air cooling must be equipped by devices/equipment for the quenching of fire by water. For this in the region of end connections the stator windings install rings of the tubes with a large number of small/fine openings/apertures through which the atomized water is fed into the machine with the quenching of fire [22-4].

Fire in the machines of the small power of low voltage can be turnned off with the aid of different movable fire extinguishers or by water from the water-conducting network/grid through fire hoses.

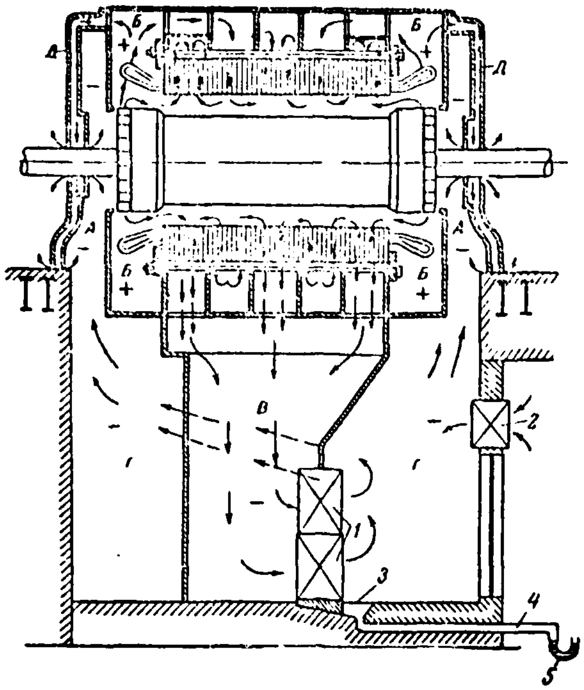

Fig. 22-2. Schematic of the closed system of ventilation of turbogenerator.

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Hydrogen cooling. In the material of the body of the rotor of high-speed turbogenerator appear the large mechanical stresses, caused by centrifugal forces, and the alternating bending stresses. Therefore the rotors of turbogenerators are manufactured from one-piece/entire forgings made of special high-quality magnet steel.

In the contemporary state of metallurgy for two-pole turbogenerators on 3000 r/min is possible the manufacture of rotors with diameter of not more than 1.1 m and whose active part is length than 6.5 m. With great difficulties is connected also the production of bindings for the reinforcement of end connections of the winding of rotor [22-5 and 22-6].

Since the power of turbogenerator in essence is determined by the thermal condition of the rotor winding, then during limitation indicated above of the sizes/dimensions of rotor proves to be that with ventilation two-pole turbogenerators it is possible to construct to the power not more than 120-140 MVA. The turbogenerators of larger power can be constructed only during hydrogen cooling. As a result of the series/row of essential advantages in comparison with ventilation hydrogen cooling is applied also for the machines of smaller power.

Are distinguished two means of the hydrogen cooling of the synchronous machines: surface and internal.

Surface hydrogen cooling is realized similarly to locked ventilation: in the closed-cycle cooling system of machine circulates one and the same space of gas, to 96-98o/o of that consisting of hydrogen. The construction/design of machine does not undergo substantial changes in comparison with machines with ventilation.

Does not change the diagram of the heat removal from the windings; as in machines with ventilation, heat from the conductors of the windings of rotor and stator is abstracted/removed through the layer of the electrical insulation of windings, on teeth and then from the surface of the latter to the cooling gas in the gap between the rotor and the stator, but on stator and to the cooling gas - in its air ducts.

Fundamental difficulty with the fulfillment of hydrogen cooling is the need of guaranteeing the explosion-proof character of machine, since the mixture of hydrogen with air (in a certain proportion) forms dangerously explosive detonating gas. Machine frame is performed by gas-impermeable; in the points of emergence of shaft butt ends from housing are provided for good oil seals. Within machine frame they support certain overpressure. So, the first Soviet machines with hydrogen cooling had the overpressure of gas in housing 0.035-0.05 Atm(gage).

Machine frames experience pressure of up to 6-10 Atm(gage) [22-6 and 22-7].

Due to overpressure in machine frame in operation occurs certain escape of hydrogen from machine, completed automatically, for example from the cylinders of compressed hydrogen, established/installed near

machine (4 in Fig. 22-3). As a result of the large space of machine room and its good ventilation this small escape of hydrogen does not cause the explosion hazard or fire.

During the work of machine with the aid of gas analyzers continuously and automatically monitor the percentage of hydrogen from the cooling system of the machine. In operation is allowed/assumed the cleanliness of hydrogen in limits not less than 96-98o/o, also, when the oxygen content in gas mixture does not exceed 2o/o.

The fundamental advantage of the system of hydrogen cooling in question consists in the fact that with constant/invariable duimensions the power of machine can be increased approximately/exemplarily to 20-30o/o in comparison with power with ventilation. Or, on the contrary, at the same power of machine its sizes/dimensions can be respectively reduced by 20-30o/o.

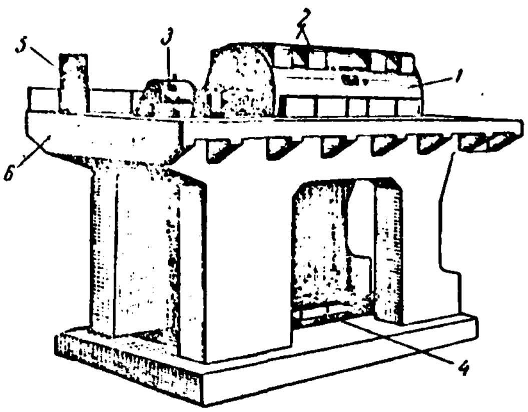

Fig. 22-3. Turbogenerator with hydrogen cooling of the type TV2-100-2 with a power of 100 MW with 3000 turns/min. 1 - turbogenerator; 2 - section of the gas condenser; 3 - driver; 4 - cylinders with hydrogen; 5 - control board of the hydrogen cooling; 6 - bed.

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Is explained this by the considerably best cooling of machine as a result of the higher coefficient of heat transfer from the surface of hot body to gas and several times of the larger thermal conductivity of hydrogen. With overpressure 0.035 Atm (gage) and cleanliness of gas 96o/o coefficient of heat transfer with turbulent, i.e., vortex/eddy, flow of cooling gas approximately/exemplarily 1.55 times more than air at the atmospheric pressure; the coefficient of the thermal conductivity of gas of the same cleanliness approximately/exemplarily 6.6 times more than air [22-5].

In high-speed synchronous machines with ventilation the losses to ventilation compose 35-50o/o of all losses of machine. These losses depend on the density of the cooling gas: the less gas density, that is less than loss. With hydrogen cooling with overpressure 0.035-0.05 Atm(gage) the density of the cooling gas is approximately/exemplarily 8-10 times less than air at atmospheric pressure. Respectively into the same number of times are less losses to ventilation, which leads to an increase in the efficiency of machine by 0.7-1o/o.

Besides those indicated, it is possible to note also the following advantages of hydrogen cooling in comparison with air [22-8]:

1. Are more the reliability of operation and the service life of insulation, is more the periodicity of repairs and is less their duration as a result of the absence of the oxidation of insulation, dirt and dampness; the corona of the wires of the stator winding in the atmosphere of hydrogen is less detrimentally for insulation.

2. There is no danger of onset of fire in machine at breakdown of insulation of windings, since hydrogen does not support

combustion; it is not required special devices/equipment for quenching of fire.

3. Is considerably less noise with work of machine as a result of less density of gas.

4. Is less surface of gas condensers as a result of larger value of factor of heat transfer (see above) and smaller total loss of machine.

5. In synchronous condensers where rings with brushes are placed in hydrogen, several times is less wear of brushes.

In the beginning of 1959 Soviet plants manufactured with surface hydrogen cooling at overpressure in housing 0.05-1 Atm(gage) the turbogenerators with a power of 30-150 MW (37.5-166.7 MVA) inclusively and the synchronous condensers in power 37.5 and 75 MVA. All these machines have a speed of rotation 3000 r/min. It is possible that in the future with a decrease in the expenditures for the equipment of hydrogen cooling can prove to be economically advisable the production with the hydrogen cooling also of synchronous machines in power less than 30 MVA.

Hydraulic generators, as has already been indicated, have only

ventilation.

As a result of considerably smaller overall sizes water gas condensers incorporate inside machine frame with hydrogen cooling. By this is removed device/equipment in the cooling system of the machine of the special well condensed chambers/cameras and ducts which raises the explosion-proof character of machine. For the creation of the necessary circulation of gas the machines are usually supplied with two fans, established/installed from both ends/faces of rotor. Heated gas leaves air ducts between the packets of steel of the stator (similarly how this is shown in Fig. 22-2) and then it passes through the sections of coolant along tubes of which flows/occurs/lasts the water.

Fig. 22-3 shows the general view of turbogenerator with a power of 100 MW with the surface hydrogen cooling, in housing 1 of which are built in eight vertical sections of 2 gas condensers. The machines of smaller power have four sections of gas condenser, located in the zone of frontal machine parts.

Soviet turbogenerators with surface hydrogen cooling at the overpressure of gas 0.035-1 Atm(gage) can work, also, with ventilation, but with the load, which does not exceed 60o/o of their nominal power (during hydrogen cooling).

The translation/conversion of machine with hydrogen to air cooling and back, which is possible with the working machine, must be conducted by full/total/complete displacement from machine in the first case of hydrogen, and the secondly - air. This is necessary for warning/preventing the formation/education of detonating gas and blast of machine. For eliminating this danger they displace from machine hydrogen or air by carbon dioxide, for which are provided for special cylinders with the compressed carbon dioxide.

Fig. 22-4 gives the simplified circuit of the hydrogen economy of turbogenerator. For supply and gas bleed in the upper and lower parts of machine frame are collectors/receptacles 11 and 12 with openings/apertures. The position of all taps/cranes in the diagram corresponds to the normal work of generator on the hydrogen cooling (closed taps/cranes are blackened).

Installation is equipped by several cylinders with hydrogen 1, compressed air 2 and carbon dioxide 3.

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The gas pressure in generator

and the cleanliness of gas (the percentage of hydrogen) are monitored by special device/equipment 4, which with the aid of by special device/equipment 4, which with the aid of tubes A and B is connected with generator. The end/lead of tube A is introduced into region after fan (high-pressure area), while the end/lead of tube B - into region to fan (diffluence). As a result of pressure difference in these regions, the gas circulates through monitor 4.

As a result of certain escape of hydrogen the gas pressure in machine is reduced, that is monitored manometer 8 and pressure relay 5. At a normal pressure of gas in generator the contacts of relay 5 are extended. With lowering in the pressure the contacts of pressure relay are closed and excite by current the coil of magnetic valve 13. The latter is opened/disclosed, and hydrogen from tank/balloon 1 through the pressure reducer by 9 and valve 13 enters through upper collector/receptacle 11 into generator. Thus, the pressure of hydrogen in generator is supported automatically (6 - manometer for the control of the pressure of hydrogen on reducer 9).

Monitor 4 has instruments, which directly show the content of hydrogen in gas. With the inadmissible decrease in the content of hydrogen in gas operates/wears the signalling device, which notifies personnel.

Monitor can work, also, with the stationary generator. For this it is necessary to shut tap/crane 23 and to discover tap/crane 24; then small gas jet will ensue/escape/flow out in the atmosphere, and monitor will work.

If it is necessary to extrude/exclude from generator hydrogen and to replace with its air, then they first displace hydrogen by carbon dioxide. Being guided by simplified circuit in Fig. 22-4, for this it is necessary to shut taps/cranes 14, 15, 22 and 23 and to discover taps/cranes 18, 19 and 21. In this case the carbon dioxide from tank/balloon 3 will enter the lower collector/receptacle of generator 12 and displace hydrogen which through upper collector/receptacle 11 and tap/crane 21 will emerge in the atmosphere (on manometer 7 is monitored the pressure of carbon dioxide). Output from the tap/crane of 21 carbon dioxide testifies about the filling with it of entire generator. Then they displace from generator carbon dioxide by air. For this must be closed

taps/cranes with 14, 15, 18, 19 and 21-24 and are opened taps/cranes 16, 17 and 20. The compressed air from tank/balloon 2 through the pressure reducer 10 enters collector/receptacle 11 and displaces carbon dioxide in the atmosphere through collector/receptacle 12 and tap/crane 20.

They analogously replace air by hydrogen. They first displace air by carbon dioxide, and then carbon dioxide by hydrogen.

With an increase of pressure p of hydrogen in machine frame the value of the coefficient of heat transfer from the surface of hot body to gas grows/rises proportional to the gas pressure to degree of 0.8, i.e., $p^{0.8}$ (at the constant velocity of gas). For example, with an increase in the overpressure from 0.035 to 1 atm(gage) the coefficient of heat transfer increases approximately/exemplarily 1.65 times, and with an increase in the pressure to 2 atm(gage) - approximately/exemplarily 2.3 times [l 22-5].

Thus, the pressure increase of gas in machine frame significantly improves its cooling. So, an increase in the overpressure of gas to 3 atm(gage) allows with the same overall sizes of machine to increase its power approximately/exemplarily to 30o/o in comparison with power at the overpressure of gas 0.035 atm(gage) (or at the same power to respectively decrease the overall sizes of

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machine). Increase in the gas pressure over 3 atm(gage) gives a comparatively small gain in the power of machine.

With surface hydrogen cooling at the overpressure of gas to 3 atm(gage) can be constructed the turbogenerators in power to 270 MVA.

Internal hydrogen cooling. By even more effective means of an increase in the power of turbogenerators is the direct internal cooling of copper of windings hydrogen at elevated pressure. In the turbogenerators with internal hydrogen cooling, which occasionally referred to as generators with the forced hydrogen cooling, the cooling gas, which is located in housing under overpressure to 3-3.5 atm(gage) and even is more, at a high speed it passes through air ducts within windings and steel of stator. Because of the elevated pressure of gas, large gas velocity in channels and the direct contact of gas with the conductors of windings is provided the intense cooling of machine. In this case the heat removal from windings the better, the less the thickness of electrical insulation, which separates/liberates gas from the metal of wire, since isolation plays the role of the thermal barrier, which impedes the heat removal.

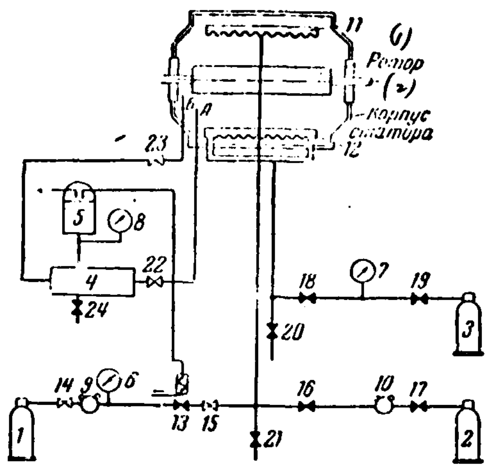

Fig. 22-4. The simplified circuit of the hydrogen economy of turbogenerator.

KEY: (1) Rotor. (2) Stator housing.

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Is especially effective the cooling, when there is no this insulation and gas is contacted directly with the metal of the conductors of winding.

Energetic cooling of coils makes it possible to considerably increase current density in the conductors of windings, and thereby also the power of the machine: the power of machines with internal hydrogen cooling 1.5-2 times approximately/exemplarily exceeds the power of the machines of the same overall sizes at surface hydrogen

cooling and overpressure 0.05 atm(gage).

In spite of an increase of the coil losses as a result of large current density and an increase in the windage losses as a result of the large pressure, developed with fans, the efficiency of machines remains approximately/exemplarily the same as during surface hydrogen cooling.

The larger cost/value of machines with internal hydrogen cooling with excess is redeemed due to the decrease of fundamental initial costs of the machine room of station as a result of the smaller sizes/dimensions of machine per the unit of power and decrease in the operating costs.

There are different constructions/designs of windings of machines with internal hydrogen cooling. Fig. 22-5 in the form of an example shows one of the constructions/designs of the slots/grooves of stator-rotor unit of generator with internal cooling.

Stator winding rationally to perform with air ducts in the form of narrow slots along the axes of the rods of winding. Structurally/constructurally such channels between two series/rows of copper are formed with the aid of special longitudinal spacers or metal tubes of rectangular cross section, as is evident in Fig.

22-5a. For decreasing the losses from eddy currents are applied the tubes with the small thickness of the walls, prepared from metal with the high specific resistor/resistance, for example, to the stainless steel. Tubes themselves insulate just as the parts of the rods of winding.

In the rotor winding, as is known, flows/occurs/lasts direct current; therefore it can be made from the copper conductors of large cross section. Applying the conductors of shaped section, it is easy to fulfill air ducts within winding. In the construction/design, shown in Fig. 22-5b, the conductors of 6 rotor windings have U-shaped form and are packed so that are formed rectangular air ducts 7. Two conductors form parallel turn; therefore there is no insulation between them. Insulation 8 between turns as the isolation of 9 windings from the body of rotor, does not have effect on cooling of the conductors of winding. The temperature of winding is determined by the temperature of gas and by the coefficient of heat transfer from copper to gas.

Turbogenerators with internal hydrogen cooling at a pressure of gas 3 atm(gage) can be made to power to 350-400 MVA.

In 1958 Soviet plants prepared the first turbogenerators with internal hydrogen cooling in power on 200 MW (235 MVA), which will

enter into operation into 1959-1960. Is conducted work on the creation of even large/coarser turbogenerators with internal hydrogen cooling in power to 300 MW.

Internal hydrogen cooling will be used also in the turbogenerators of smaller power. Is developed and is mastered the new series of turbogenerators with internal hydrogen cooling with a power of 30 MW (37.5 MVA) and above (type TVF, where Ф - the forced cooling).

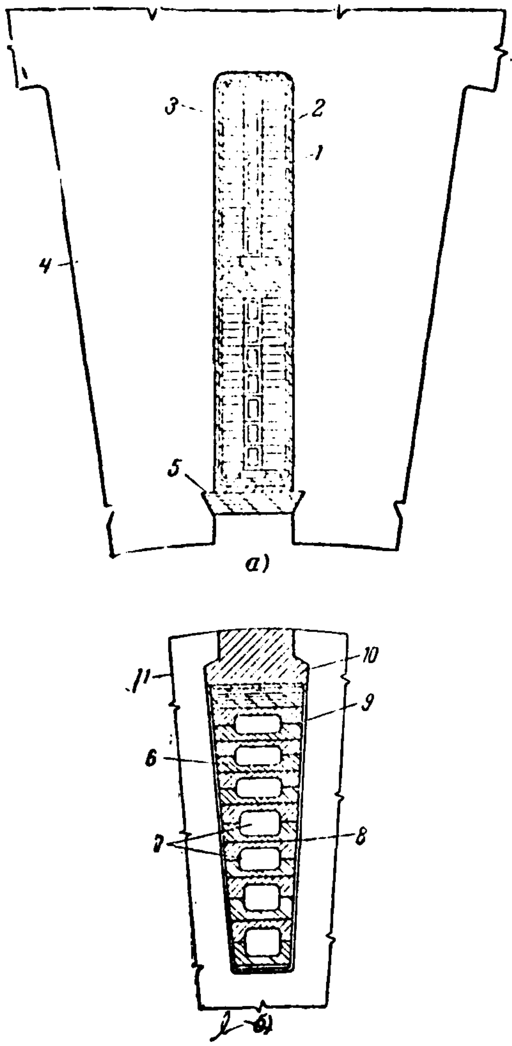

Fig. 22-5. Diagrams of the slots/grooves of turbogenerator with internal hydrogen cooling. a) the slot/groove of the stator; b) the slot/groove of rotor. 1 - conductors of the stator winding; 2 - insulation; 3 - air ducts; 4 - sheet of the core of the stator; 5 - key; 6 - conductors of the rotor winding; 7 - air ducts; 8 -

insulation; 9 - sleeve; 10 - key; 11 - body of rotor.

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The turbogenerators of new series have smaller overall sizes and weigh to 30-35o/o less than turbogenerators with the surface hydrogen cooling of series TV2 [22-9].

The internal liquid cooling of the windings of machine provides good heat removal and it makes it possible to substantially decrease the overall sizes and the weight of turbogenerators and to considerably increase their ultimate capacity. As the cooling fluid it is possible to utilize transformer oil or distilled water.

Cooling efficiency by liquid characterize the following data: the cooling capacity of transformer oil approximately/exemplarily into 7, and water approximately/exemplarily 16 times the more than cooling capacity of hydrogen at a pressure 2 atm(gage), or respectively into 21 and 50 times more in comparison with the cooling capacity of air at atmospheric pressure.

It is interesting to note that the effectiveness of internal hydrogen cooling is compared with the effectiveness of oil cooling only under creation condition in machine frame of the overpressure of

gas on the order of 5-6 atm(gage) [22-5]. However, at such pressures appear serious difficulties in the relation to the guarantee of mechanical strength and airtightness of housing and creation of proper multiplexing.

The use of a liquid for cooling the rotor is connected with some structural/design difficulties. In connection with this can be made the mixed cooling system: the liquid cooling of the stator winding and the internal hydrogen cooling of the rotor; steel of stator is cooled by hydrogen.

With internal liquid cooling the stator windings the latter perform from the hollow rectangular copper conductors, within which circulates the liquid, or inside rods the stator windings embed the thin-walled steel tubes over which flows/occurs/lasts the liquid (it is similar to channels 3 for gas in Fig. 22-5a). On both ends/faces of the stator the channels indicated, over which flows/occurs/lasts the liquid, are united by the collector rings, connected by conduits/manifolds with tank and pump, which supports the permanent circulation of liquid in the channels of winding. In order that the liquid not penetrate in machine frame, the pressure of it must be less than the gas pressure in housing.

Calculations show that with liquid cooling can be created the

turbogenerators in power to 500-600 MVA in unity, and possibly, and large/coarser.

Soviet plants project/design and conduct preparation for the production of turbogenerators 300 MW and larger power with the water cooling of stator and the internal hydrogen cooling of rotor, and also with the water cooling of both stator and rotor.

It is possible that subsequently the internal liquid cooling, as substantially decreasing the overall sizes and the weight of machine, will be applied, also, in the machines of smaller power.

22-3. Driving circuits.

The excitation of each alternator in the majority of the cases is realized from separate direct-current generator, called driver. The armature of excitation either is fit/mounted shaft butt end of the rotor of machine or has its separate shaft, connected by clutch with the rotor shaft of machine.

As drivers are applied the direct-current generators with parallel (shunt) excitation (Fig. 22-6). The power of driver composes 0.25-1o/o and somewhat more than (for small machines) the power of the synchronous machine (see Table P-1 and P-3). Nominal voltage of

drivers usually 65-450 V (for small machines - less than 65 v, but for very large/coarse ones - more than 450 V ; for example, the nominal voltage of the drivers of the hydraulic generators of the Volga hydroelectric power plant im. V. I. Lenin accept by 800 V).

The system of the excitation of machine must be made with maximum reliability. To inadmissibly utilize a driver for other any purposes besides excitation.

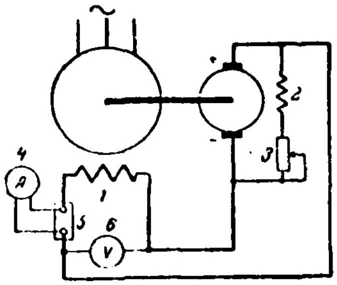

Fig. 22-6. Schematic diagram oi tue dynamoelectric excitation of synchronous machine.

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Fig. 22-6 gives ncrmal drivinj circuit of alternators and compensators. In the circuit oi tne excitation winding of driver 2 is connected shunt rheostat 3, wnich uses for manual field control of machine (coil current of rotor 1).

Ammeter 4 serves for tue control/checking of the load of the circuit of rotor. The field current of average/mean and large/coarse machines usually is sufficiently great; therefore ammeter 4, as a rule, they connect across shunt 5. Voltmeter 6 makes it possible to monitor a change in the voltage of the driver when launching/starting the machine; it use also during tne determination of power consumption per excitation macnines.

In energizing circuits of safety fuses they do not install, since during the use of a driver only according to straight/direct designation/purpose its unforeseen overloadings are impossible, but short circuits upon the precisely executed connection of driver to the brushes of rotor little are probable.

As a result of the large rate the rotations of turbogenerators in operation take the place of the damage of their drivers (mainly collectors/receptacles). Therefore on power plants with turbogenerators compulsorily is provided for the stand-by excitation, which allows in the case of damaging the working driver of generator to rapidly transfer the feed of his excitation winding to stand-by driver without the cutoff/disconnection of turbogenerator.

As stand-by driver is installed the direct-current generator, led to rotation by asynchronous squirrel-cage motor.

On hydroelectric power plants at a comparatively low speed the rotations of the hydraulic generators of the damage of drivers are very rare; therefore stand-by excitation on them usually does not provide for [13-2 and 22-1].

If turbogenerator lost excitation as a result of any reason, not requiring its immediate cutoff/disconnection (for example, with the erroneous cutoff/disconnection of driver, the incorrect turn of wheel of shunt rheostat, break in energizing circuit of driver, etc.), then it can short-term (to 30 min) work in asynchronous mode/conditions, continuing to bear certain active load and consuming from network reactive power for magnetization.

The possibility of the work of turbogenerator with refusal of excitation is explained by the fact that during asynchronous mode/conditions in the damping circuits of rotor, and if excitation winding is locked, then also in it are induced currents, as in the rotor of asynchronous machine, and generator works as induction generator (rotor rotates with speed somewhat larger synchronous). After the elimination of the reason, which caused the refusal of excitation, or switching to stand-by driver is restored the normal excitation of generator and smoothly it is pulled into synchronism. The aforesaid is not related to hydraulic generators, turbogenerators with wire bindings, or to the generators whose tests showed the inadmissibility of asynchronous mode/conditions. These generators with refusal of excitation should be immediately disconnected from network.

In recent years increasing use/application finds also the ionic

excitation of synchronous machines, i.e., the excitation by their rectified current of different converters of the variable/alternating current to direct: mercury rectifiers, ignitrons, dry rectifiers, and so forth. This excitation system possesses certain substantital advantages in comparison with a dynamo electric system. Thus, with damage in the system which is accompanied by a deep reduction in voltage, ionic excitation provides a more rapid automatic change and a higher value of excitation current and, consequently of the emf of the generators which increases considerably the stability of their multiple operation.

As a result of the great operating reliability and the possibility of the rapid replacement of any element of the system of ionic excitation is not required the device/equipment of stand-by excitation.

It is especially expedient to apply ionic excitation in powerful/thick synchronous machine s with the high currents of excitation. It suffices to indicate that in the turbogenerators with a power of 200 MW with internal hydrogen cooling the field current reaches 1750-1900 A, and in more powerful/thick machines even 3000 A.

It is logical that to remove/take such currents with the collector/receptacle of high-speed driver is very difficult; it is difficult to ensure reliable to both such powerful/thick drivers. Therefore powerful/thick turbo- and hydraulic generators and synchronous condensers, as a rule, will be manufactured with ionic excitation.

Let us become acquainted briefly with two systems of the ionic excitation; system of separate excitation and system of self-excitation [22-10 and 22-11].

System of the independent ionic excitation (Fig. 22-7a). On one

shaft with the main generator G are established/installed auxiliary polyphase alternator VG and its driver VVG (shunt self-excited oscillator, adjusted by shunt rheostat ShR). Auxiliary generator supplies the rectifying device/equipment V, from which the rectified current enters the winding of the rotor of generator G.

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Advantages of this system of the excitation: the independence of excitation system from the mode/conditions of the work of generator and station as a whole, simplicity of fulfillment, comparatively small area, necessary for positioning/arranging the equipment. Deficiencies/lacks: the presence of auxiliary generator and its driver.

The system of self-excitation (Fig. 22-7b) is realized with the feed of rectifying device/equipment V directly from the terminals/grippers of alternator G through injector transformers VT and fundamental transformer T.

With an increase of the circuital current of generator increases load voltage of secondary winding VT. Therefore are provided stable excitation and possibility of a rapid change in the field current of generator with emergencies in the system when line voltage decreases,

and circuital current of generator increases.

In this system are absent the auxiliary rotary machines; therefore the cost/value of equipment and its weight are less.

Deficiencies/lacks: the more compound circuit of connections and the need for separate source for the short-term feed of the excitation of generator during launching/starting.

For powerful/thick turbogenerators can find use the system of separate excitation with the machine of alternating high-frequency current and the dry-disc rectifiers, similar to that given on Fig. 22-7a [l 22-9].

As the supplies of power of the excitation of small synchronous machines it is possible to utilize the dry-disc rectifiers, connected directly to the terminals/grippers of the same generator. Because of the absence of driver are reached the considerable reduction of prices of aggregate/unit and simplification in the operation at the sufficiently high reliability of excitation system.

22-4. Automatic extinction of magnetic field.

The automatic extinction of magnetic field serves for the rapid

decrease of emf and, consequently, also current in the stator of synchronous machine during internal damages in it, for example, short circuits. For understanding this let us turn to diagrams in Fig. 22-8. Let us assume that with the multiple operation of two generators occurred the two-phase short circuit within generator G-1 (Fig. 22-8a). Through the place of damage in it (between points 1 and 2) will flow/occur/last the short-circuit current $I_{\kappa 2}$ from generator G-2 and short-circuit current $I_{\kappa 1}$ from the damaged generator G-1. In this case operates/wears relaying from the internal damages of generator G-1 and it is disconnected from network by switch V-1. However, also after this through the place of damage continues to flow/occur/last current $I_{\kappa 1}$ (Fig. 22-8b), since generator G-1 remains excited and it continues to rotate. To reduce the current $I_{\kappa 1}$ to zero is possible only by the path of the rapid decrease of emf of generator, that also is reached by the field discharge of excitation.

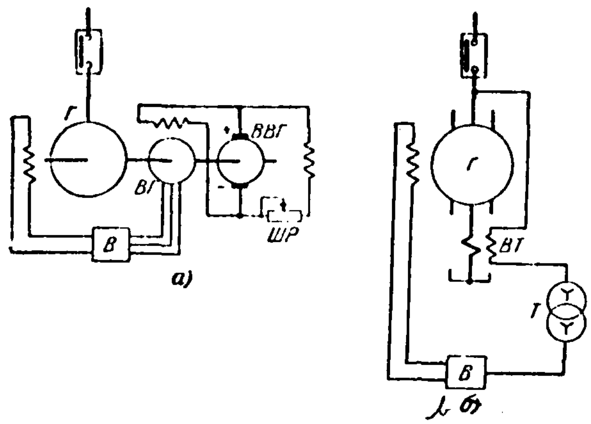

Fig. 22-7. Schematic diagrams of the ionic excitation of synchronous machines. a) the diagram of separate excitation; b) the diagram of self-excitation.

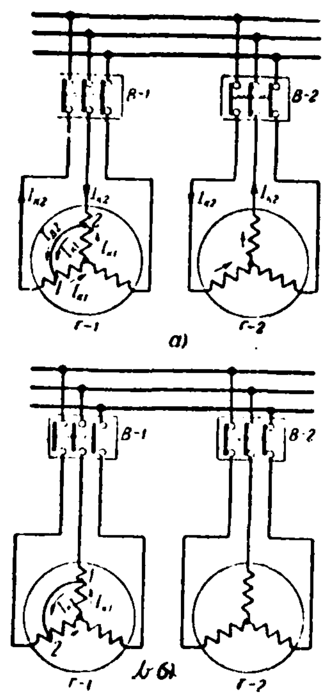

Fig. 22-8. Internal short circuit in generator.

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Short circuits within machines usually appear through the electric arc; therefore the prolonged course of fault current is very dangerous for the machine: are possible the considerable damages of winding and steel of stator. This all the more probable since current I_{k1} can be more than short-circuit current during external short circuit (on terminals/grippers). Follows this of the fact that with emf of stator changes proportional to a number of turns of winding,

and inductive winding impedance changes proportional to the square of a number of turns.

Thus, during internal damages in machine it is necessary to more rapidly possible disconnect it from network and to extinguish its magnetic field; then arc in the place of damage rapidly goes out and the damage of machine will be small. The electromotive force of machine must be reduced to such value at which the electric arc cannot be supported within machine. It is experimentally established/installed, that the arc in the place of short circuit in machine goes out with emf of less than 500 V.

In accordance with that presented all alternators, compensators and large/coarse synchronous electric motors are compulsorily equipped with devices/equipment for the automatic extinction of magnetic field. On Soviet electrical devices widest application found two methods the extinctions of the magnetic field of the machines: 1) by closing/shorting the excitation winding (rotor) of generator of active discharge resistor with the subsequent cutoff/disconnection of this winding from driver even 2) with the aid of automaton with arc-suppression grating.

The schematic diagram of device/equipment for an automatic field discharge using the first method is given in Fig. 22-9. In the

circuit of excitation winding 1 are connected the automatic field damper AGP and discharge resistor r. During the normal work of machine contacts 3 are locked, and contacts 4 are extended; discharge resistor is disconnected (Fig. 22-9a).

During functioning of AGP are first closed contacts 4 and resistor/resistance r is connected in parallel to excitation winding 1. With certain delay are broken contacts 3, which disconnect driver 2. As a result the excitation winding is closed to discharge resistor, and driver is disconnected (Fig. 22-9b). Excitation winding is changed over to discharge resistor without chain cleavage how is prevented the onset in energizing circuit of the dangerous for its insulation overvoltages which could arise with the chain cleavage of excitation, possessing considerable inductance.

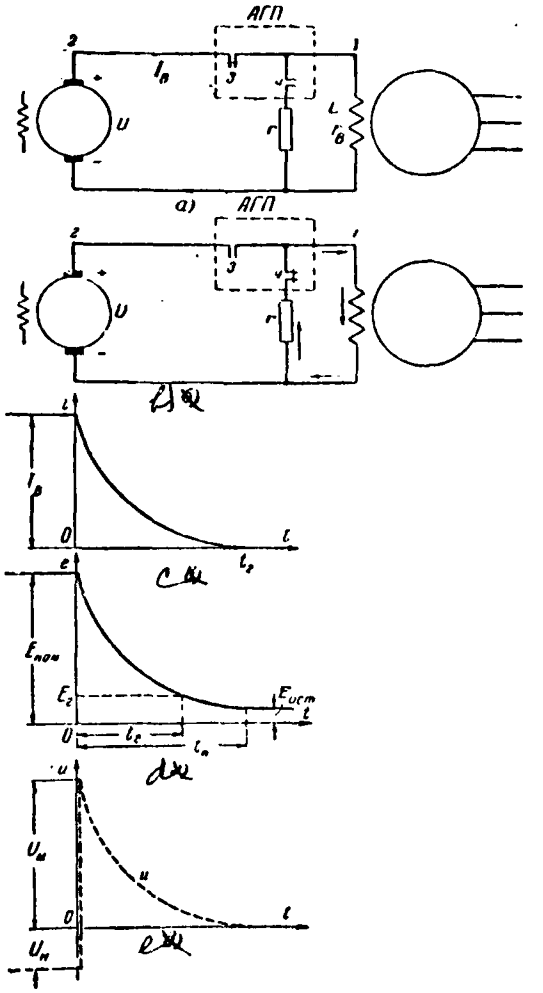

Fig. 22-9. Damping of magnetic field by switching the excitation winding of machine to discharge resistor. a) AGP is connected; b) AGP is disconnected; c) a change of the coil current of the excitation of the generator; d) a change in emf of the stator of the generator; e) a change in the voltage on excitation winding (on the rings of

rotor).

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After functioning of AGP in the formed locked outline the current is supported to those pores (it is shown by rifleman/pointers in Fig. 22-9b), until the magnetic energy, stored up in the circuit of excitation winding and equal to $\frac{LI_{в}^{2}}{2}$. is consumed for heating of discharge resistor and excitation winding:

$$\frac{LI_{в}^{2}}{2}=\int_{0}^{t_{п}} i_{в}^{2}(r_{в}+r)\,dt, \qquad (22\text{-}1)$$

where $r_{в}$ - field resistance;

L - inductance of excitation winding;

$I_{в}=\frac{U}{r_{в}}$ - field current, which precedes field discharge (here U - load voltage of driver);

$i_{в}$ - instantaneous value of field current, which changes from $i_{в}=I_{в}$ to $i_{в}=0$;

r - discharge resistor;

$t_{п}$ - the full/total/complete time of the extinction of the magnetic

field of machine.

Coil current of excitation changes depending on the time constant of closed circuit $T=\frac{L}{r_в+r}$ the equation:

$$i_в=I_в e^{-\frac{t}{T}}, \qquad (22\text{-}2,a)$$

which is graphically shown in Fig. 22-9c.

A change in the field current of machine leads to the appropriate decrease of its emf (Fig. 22-9d). After time t_r of emf of the stator it decreases to value E_r, with which the arc goes out and the course of short-circuit current in machine ceases. For the full/total/complete time of extinction $t_п$ of emf of stator it decreases to certain residual/remanent value $E_{ост}$, it is which caused by remanent magnetism of machine.

From formula (22-2a) it is evident that with an increase of the effective resistance of circuit $(r_в+r)$ the circuital current of excitation attenuates more rapidly, and the full/total/complete time of extinction decreases.

A change in the magnetic flux, engaged with the excitation winding, which possesses the considerable inductance L, causes the induction in it of emf $\left(E=-\frac{d\Phi}{dt}\right)$, therefore the field discharge of

machine is unavoidably accompanied by certain overvoltage, the larger, the more rapid decreases the field current, i.e., the greater the discharge resistor.

In normal mode load voltage of excitation winding 1 comprises $U_н = I_в r_в$. At the moment of interrupting the contacts 3 of AGP entire current $I_в$ flows/occurs/lasts through discharge resistor of r and load voltage of excitation winding it becomes equal to $U_м = I_в r$ (Fig. 22-9e). Further this voltage changes exponentially:

$$u = U_м e^{-\frac{t}{T}}. \qquad (22\text{-}28)$$

The time constant T was discussed above.

The multiplicity of overvoltage is determined by relation $\frac{U_м}{U_н} = \frac{r}{r_в}$, which greater, the greater the value of discharge resistor r.

Certain effect on the process of the extinction of magnetic field have the damping outlines of the rotor of synchronous machine. With a change of the magnetic flux of excitation in the damping outlines of rotor appear the currents, which create the magnetic flux, which supports the decreasing magnetic flux of excitation. As a result this more slowly decrease magnetic flux excitations and emf of stator, i.e., the time of field discharge somewhat increases. At the same time decreases overvoltage on excitation winding.

Device/equipment for an automatic field discharge must be made so that with least possible time of field discharge overvoltage on excitation winding would not exceed the value, permitted for its insulation. For Soviet machines great overvoltage on excitation winding (on the rings of rotor) usually is allowed/assumed more four-five times value of the nominal voltage of excitation winding $\left(\frac{U_{м}}{U_{ном}} < 4 \div 5\right)$. In accordance with this in devices/equipment for an automatic field discharge applies discharge resistors whose value 4-5 times usually exceeds ohmic field resistance of machine, measured in hot state [22-12]. In this case the full/total/complete time of field discharge $t_{п}$ usually reaches 6-8 s when $E_{ост}$ order 100-250 V.

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Fig. 22-10 gives the fundamental circuit diagram of the excitation of machine, to which is connected the dismantled/selected above device/equipment for the automatic extinction of magnetic field, which consists of the automatic field damper AGP and two discharge resistors to 3 and 4. On the designation/purpose of discharge resistor to 3 it is shown above. Discharge resistor 4, connected into the circuit of the excitation winding of 2 drivers and normally shortened/shorted out by contacts 7 of AGP, serves for

warning/preventing the excessive increase in load voltage of driver after its cutoff/disconnection from the excitation winding of machine. This increase in the voltage all the more probable since during short circuit the established/installed on generator automatic field regulator (see below) it considerably increases the excitation of driver. The value of this resistor/resistance is usually 10 times more than ohmic field resistance of driver in hot state [8, 22-12].

As AGP is used the latched-in contactor which has clutch magnet VE, electromagnet of trip EZ, three main (power) contacts 5-7 and blocking contacts 8-10.

All network elements Fig. 22-10 shows in the position, which corresponds to the normal work of the generator (switching the excitation wind of generator of stand-by driver is not shown).

During the damage of machine operates/wears established/installed on it relaying (in the diagram it is not shown) and it actuates auxiliary relay RP. The latter operates/wears and through its front contacts 13 closes the circuit of the disconnecting electromagnet OE of the drive of the switch V which is disconnected. Through back contacts of 14 relays simultaneously are closed the circuits of the electromagnet of trip EZ and clutch magnet VE. The latter will somewhat mix the movable system of contactor to sides

"on" (to the left on diagram), which decreases pressure trip 12, after which magnet core EZ is pulled inside its coil and trip 12 is displaced upward. In this case contacts 9 they disrupt the circuit of electromagnet VE, after which under spring effect 11 of AGP it is disconnected (movable system of contactor is moved on diagram to the right). Are first closed main contacts 5, and then are broken contacts 6 and 7. During interrupting of the latter into energizing circuit of driver is introduced resistor/resistance to 4, which decreases the field current of driver. Are simultaneously broken blocking contacts 8, which disrupt the circuit of electromagnet EZ, and contacts 10 are closed, than the circuit of electromagnet VE it prepares for the subsequent process/operation of start of AGP.

Is provided remote control of AGP with the aid of the key/wrench of control KU. In the diagram is shown the simplest pushbutton key/wrench of control. Start of AGP is realized by a pushing of the knob V, through which is closed the circuit of clutch magnet VE. Is remotely AGP disconnected by knob/button O (cutoff/disconnection occurs in the same order, as with automatic cutoff/disconnection under the action of relaying).

The signaling of position of AGP (in the diagram in Fig. 22-10 it is not shown) usually is realized by two tubes (it is connected, it is disconnected) whose circuits are changed over by supplementary

blocking contacts, similar to the circuits of signal lamps in the diagram of electromagnetic actuator in Fig. 18-11.

The dismantled/selected device/equipment of AGP can be performed, also, with the two-pole chain cleavage of the excitation winding of machine.

On small generators and synchronous electric motors apply the entreated device/equipment of AGP with introduction the resistors/resistances only to energizing circuit of driver.

A large/coarse deficiency/lack in the examined device/equipment for the automatic extinction or magnetic field is the considerable time of extinction and, consequently, also the time of the liquidation of internal damages in machine.

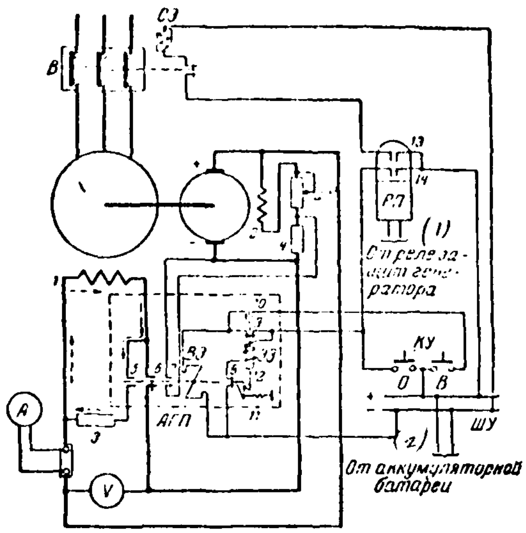

Fig. 22-10. Fundamental circuit diagram of the excitation of machine with the automatic extinction of magnetic field by switching excitation winding to discharge resistor.

Key: (1). From the relay of the protection of generator. (2). From storage battery.

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In connection with this in recent years ever more wide application obtains the second method of the extinction of magnetic field with the aid of the automata with arc-suppression gratings, developed at plant "electric power" [14-1, 14-2 and 22-14].

Fig. 22-11 gives the schematic diagram of this method of field discharge. Automaton consists of working 1 and arc-suppression 2 contacts and arc-suppression gratings 2 with copper plates 4 and shunting ohmic resistances 5. Furthermore, in automaton are permanent magnets, not shown in the diagram, which create the transverse magnetic field H.

With the cutoff/disconnection of automaton first are broken the make contacts of 1 automata (Fig. 22-11a), and then after the small time its arcing contacts 2. The electric arc, which appears on arcing contacts under cross-magnetizing effect H rapidly enters into the arc-suppression grating whose copper plates cut it into the series/row of short arcs.

Voltage on short arc in essence is determined by the sum of cathode and anode drops and over a wide range of currents retains the constant value, which does not depend on the value of circuital current.

With the comparatively little heated copper electrodes voltage on short arc $U_{к.д} \approx 20 \div 25$ V. Therefore with n gaps/intervals between the plates of arc-suppression grating the common voltage, necessary

for arc maintenance in the grating of automaton, comprises $U_д = U_{к.д} n$.

Thus, at the moment of the entry of arc into the grating of automaton voltage on it immediately grows/rises to value $U_д$ and virtually it remains constant/invariable to arc extinction, after which it decreases to the value, equal to emf of the driver (energizing circuit of generator is brought).

Voltage $U_д$ is directed against the voltage of driver; therefore circuital current of the excitation of generator decreases and the more rapid, the greater voltage, i.e., the greater a number of plates of the grating of automaton. With small ohmic field resistance of current generator in its circuit changes rectilinearly from $I_в$ to zero (Fig. 22-11b). With reduction in current of excitation decreases emf of generator.

Voltage on the winding (on rings) of rotor (on terminals/grippers a and b) in normal mode is equal to voltage $U_н$ of driver. With striking of the arc in the grating of automaton this voltage changes its sign and becomes equal to $U_м = U_в - U_д$, and after arc extinction in grating, i.e., the end of the process of field discharge, it drops to zero (Fig. 22-11b).

An increase in the number of plates of the arc-suppression

grating of automaton leads not only to the acceleration of the field discharge of machine, but also to an increase in the voltage on arc-suppression grating, but thereby also to an increase in overvoltage $U_м$ on the excitation winding of generator. Therefore a number of plates of grating is selected from this calculation that the overvoltage on the excitation winding of machine would not exceed four-, quintuple value of nominal voltage. Under this condition the full/total/complete time of field discharge with the use of an automaton with arc-suppression grating proves to be 6-10 times of less than the full of time extinction with closing/shorting of excitation winding to discharge resistor (on diagram in Fig. 22-9).

With a large number of short arcs in arc-suppression grating always can be created such conditions, under which one of the arcs is deionized more rapidly than others. However, the extinction of arc in one of the gaps/intervals leads to the simultaneous extinction also of all other arcs, and consequently, to rapid reduction in current to zero and considerable overvoltage in circuit.

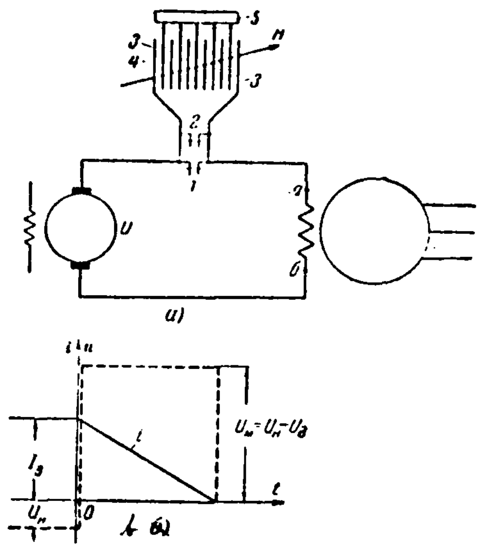

Fig. 22-11. Extinction of magnetic field with the aid of automaton with arc-suppression grating. a) the schematic diagram; b) a change in the field current and voltage on excitation winding (on the rings of rotor).

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For warning/preventing the overvoltages indicated in parallel to the sections of arc-suppression grating are connected backs-out resistor (5 in Fig. 22-11a). The arc, shunted by resistor/resistance, goes out at that moment/torque when arcs currents and back-out resistor become equal. The arc, shunted by smaller resistor/resistance, goes out earlier than the arc, shunted by high

resistor/resistance. By the appropriate selection of backs-out resistor they attain the specific sequence of arc extinction in the sections of grating. By the latter go out the arcs between those plates which do not have backs-out resistor.

The resistors/resistances, which shunt the sections of arc-suppression grating, barely manifest themselves the duration of field discharge.

The fundamental circuit diagram of the excitation of machine with the use of an autcmaton of the type AGP-1 is given in Fig. 22-12. Switching the excitation winding of generator of stand-by driver is not shown. Position of all network elements is given with the normal work of generator.

Automaton is equipped with electromagnetic actuator of the type PS-10 with switching on VE and disconnecting OE by electromagnets. Furthermore AGP-1 has the disconnecting release whose electromagnet EOR in the electrical circuit of control is connected in parallel with OE of drive. The time of action of release - order 0.04-0.06 s, i.e., is less than the time of action OE of drive PS-10. Therefore virtually AGP-1 is disconnected under the action of release, and disconnecting electromagnet OE of drive it appears as reserve to release.

Automaton AGP-1 has only one pair of main contacts 3 (contacts 5-7 - blocking); therefore for shorting of resistor/resistance to 4 in energizing circuit of driver is established/installed special contactor K_{s} with normally closed contacts. With cutoff/disconnection of AGP-1 through its blocking contacts 6 is closed the circuit of the holding magnet of contactor K_{s}, whose contacts are broken, and resistor/resistance to 4 is introduced into energizing circuit of driver. Upon start of AGP-1 contacts 6 are broken, contactor K_{s} is disconnected and shunts resistor/resistance to 4. The diagram of control of electromagnetic actuator is made so, as this was shown in Fig. 18-11 (signal lamps in the diagram Fig. 22-12 was not show). In other respects the diagram in Fig. 22-12 explanations does not require.

In certain cases the diagram of control of automaton AGP-1 is performed so that it would be disconnected only during functioning of relaying. With all operating cutoffs/disconnections of machine AGP-1 it remains connected, and field discharge is realized only with the aid of contactor K_{s}, by the introduction of resistor/resistance to 4 to energizing circuit of the driver (supplementary indications about the execution of driving circuits of generators with use for the field discharge of automata with arc-suppression gratings are

presented in § 22-6, also, in Fig. 22-20).

The arc-suppression gratings of an automaton of the type AGP-1 are made from the copper disks with a thickness of 2 mm, mounted to the isolated/insulated steel cylinder with the gaps/intervals between the disks, equal to 1.5 mm.

Through every 10-11 plates between disks are placed the coils, about which flow arc current after its entry into grating. These coils create radial magnetic field. Short arcs, after catching into this field, start up around the axis of grating. The rapid displacement/movement of arcs prevents/warns the surface melting of plates in the process of field discharge.

The arcing contacts of automaton are equipped with caps of the cermet connection tungsten - silver. All this provides high reliability of the work of automata of the type AGP-1. The rated current of these automata - to 3000 a.

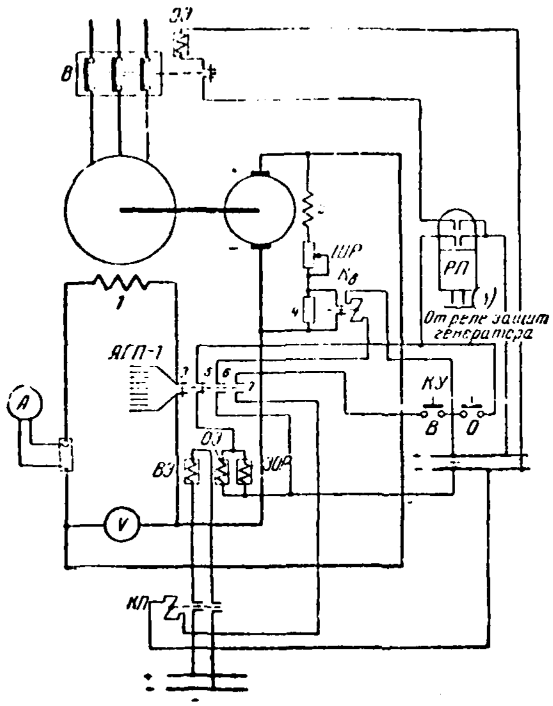

Fig. 22-12. Fundamental circuit diagram of the excitation of machine during the use/application of an automaton of damping of a field of the type AGP-1.

Key: (1). From the relay of the protection of generator.

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At present all Soviet machines with a power of 30-50 MW and are above supplied with the automatic field dampers with arc-suppression

gratings.

At plant "Electric power" is developed and is mastered the series of the automatic field dampers with arc-suppression gratings, calculated for rated currents 150, 300, 600, 1200 and 2400 a. Such automatic field dampers will be applied on all small ones and large/coarse turbo- and hydraulic generators of all power to 200 MW inclusively. The automatic field dampers of new series are considerably simpler structurally/constructurally, have substantially smaller sizes/dimensions in comparison with automata of the type AGP-1 and it is very reliable [14-2].

22.5. Automatic field control.

As noted earlier, for increasing the reliability of the nourishment of users high value has voltage recovery rate after the cutoffs/disconnections of short circuits. It was noted also that for increasing the stability of the multiple operation of generators and stations of system in short circuits the vital importance has increase emf. To achieve that, etc. with the aid of manual field control by rheostats is impossible. Therefore they resort to the devices/equipment of automatic field control which under normal conditions facilitate the work of attendant personnel on the maintenance of the assigned voltage on the busbars of installation

and the distribution of reactive load between machines, but during short circuits they automatically increase the excitation of machines to limiting ("ceiling") value.

In normal mode automatic field control provides the maintenance of the assigned voltage on busbars with oscillations/vibrations within limits of ±0.5-1o/o. During the relatively distant short circuits automatic field regulators provide higher stress level on the busbars of station.

Relay over-excitation. The simplest automatic device/equipment, which increases during short circuits the excitation of machines to certain limiting value, is relay over-excitation (Fig. 22-13). This device/equipment is made with the aid of undervoltage relay H<, connected to secondary winding of voltage transformer TN, and single-pole contactor K with normally open contacts.

During the short circuits, which are accompanied by decrease in the voltage on 15o/o and more, undervoltage relay operates/wears and closes the circuit of the electromagnet of contactor K. The latter is included and short shunt rheostat ShR. The excitation winding of driver is included to the total voltage of driver. Circuital current of excitation rapidly increases, and load voltage of driver grows/rises to the "ceiling" value, which depends on the parameters

of driver and excitation winding of machine. Simultaneously to certain maximum value increase field current machines and its emf.

After the cutoff/disconnection of short circuit and resumption of voltage undervoltage relay it breaks its contacts, and contactor K is disconnected, introducing by shunt rheostat into energizing circuit of the driver: is restored the normal mode of the work of machine.

From all that has been previously stated, it follows that the relay over-excitation is not actually voltage regulator. Its designation/purpose is reduced only to a maximum increase in the excitation of machine during short circuits, that also provides an increase in the stability of multiple operation and accelerates resumption of voltage after the cutoff/disconnection of short circuits.

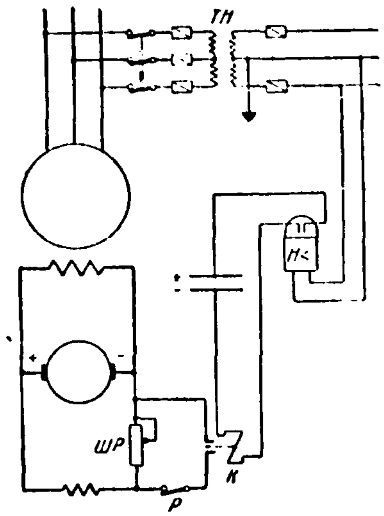

Fig. 22-13. Relay over-excitation of machine.

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The device/equipment of over-excitation one should to switch on in work immediately after the start of machine on network, and disconnect only after the cutoff/disconnection of machine from network. If machine is stopped, and the device/equipment of over-excitation is not disconnected, then contactor K remains long connected, but rheostat ShR - shortened/shorted out, that it does not make it possible to use the latter during launching/starting of the machine (see §22-6). Tripping device over-excitations by knife switch or key/wrench R, established/installed on panel or panel of the corresponding machine on control board. Relay over-excitation is

installed in all synchronous machines independent of the type of the established/installed on them automatic field regulator [8-2 and 22-1].

Compounding of synchronous machines. At present on Soviet installations for automatic field control of synchronous machines most use extensively the devices/equipment compoundings, developed by the series/row of scientific workers (L. V. Tsukernik, S. A. Lebedev), and also by the workers for Moscow and Ural power systems and technical control MES.

The compounding of synchronous machines is realized via the injection of the excitation winding of driver by rectified current from current transformers, connected into the circuit of stator. Current is straightened/rectified by the selenium rectifiers.

The simplest diagram of compounding is given in Fig. 22-14a.

From current transformers TT, connected during three phases of the circuit of the stator of machine, is supplied three-phase transformer TK of the compounding device/equipment, to secondary winding of which is connected the group of selenium rectifiers V-1, connected on three-phase bridge circuit. Unidirectional voltage is fed/conducted to excitation winding OV of driver.

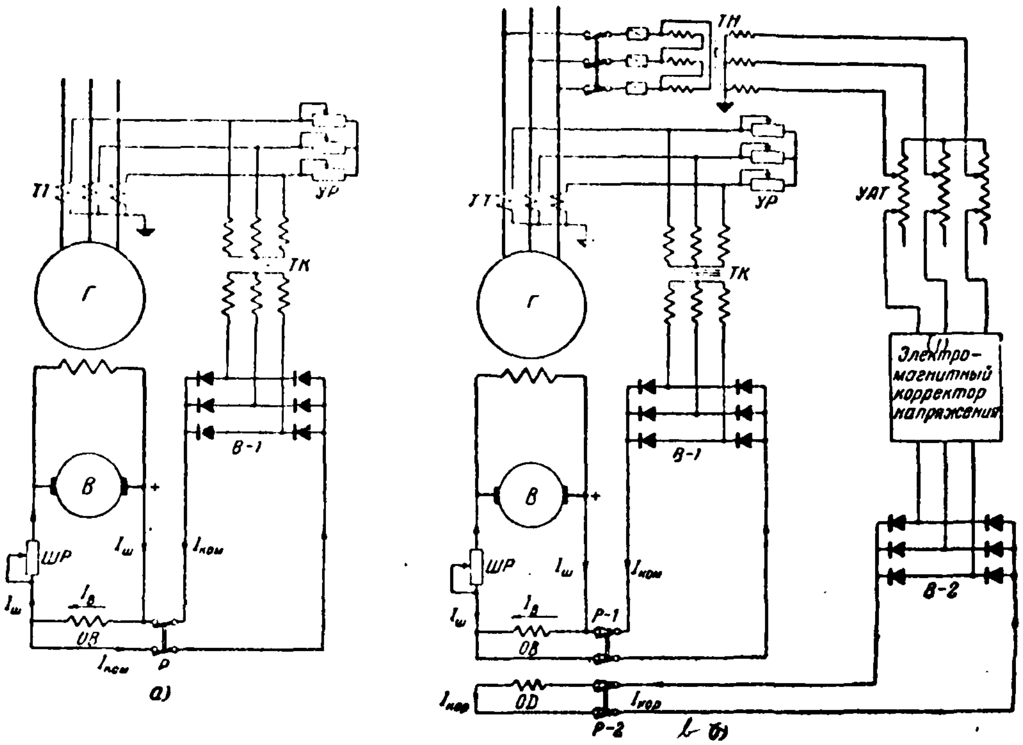

Fig. 22-14. Schematic diagrams of the compounding of the excitation of synchronous machines.

Key: (1). Electromagnetic corrector of voltage.

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Thus, to the latter are in parallel connected two current sources: driver V and rectifiers V-1. The first gives current $I_ш$, and

the second - current $I_{ком}$. In the excitation winding of driver flows/occurs/lasts current $I_{в} = I_{ш} + I_{ком}$.

The strength of current $I_{ш}$ depends on the position of shunt rheostat ShR.

The strength of current $I_{ком}$ with the constant/invariable load of synchronous machine depends on the position of adjusting rheostat UR: with a change in the introduced resistor/resistance of the latter changes the value of the voltage, applied to transformer TK and, consequently, also the value of rectified current $I_{ком}$. The necessary position of adjusting rheostat UR is selected during the adjustment of the compounding device/equipment.

It is not difficult to see that with an increase in the load of synchronous machine and during short circuits current $I_{ком}$ increases, in consequence of which increases the excitation of machine. With the decrease of the load of machine current $I_{ком}$ decreases, and consequently, decreases its excitation.

Usually is realized the so-called "normal compounding", which consists in the fact that with the shunt rheostat, established/installed in the position of the idling of machine, an increase in its excitation with the increase of load from idling to

nominal completely is provided due to compounding without effect on adjusting rheostat.

The insensitivity of the compounding device/equipment is in effect equal to zero, since with any change in the current of the load of machine changes its excitation.

Deficiencies/lacks in the dismantled/selected device/equipment: 1) does not provide strict constancy of voltage on busbars with all operating changes in the load; 2) do not provide rapid resumption of voltage after the cutoff/disconnection of short circuit, since after the cutoff/disconnection of short the current of machine decreases to normal and decreases the injection of the excitation winding of the driver; 3) do not provide the necessary boosting with relatively small stable decreases in the voltage.

For the purpose the eliminations of the deficiencies/lacks indicated the compounding device/equipment supplement by the electromagnetic corrector of the voltage whose connection is schematically shown in Fig. 22-14b.

Designation/purpose of the corrector of voltage - change of exciting the synchronous machine with all voltage errors from the assigned for the purpose of restoration/reduction of the assigned

voltage.

The corrector of voltage is supplied from the group of voltage transformers TN through the adjusting autotransformer UAT, which makes it possible during tuning of corrector to change the conducted/supplied to it voltage. Corrector supplies the group of the rectifiers V-2, from which rectified current $I_{\text{кор}}$ (current of corrector's output) enters the supplementary excitation winding OD of driver, creating the supplementary excitation of driver, and thereby synchronous machine itself.

The electromagnetic corrector of voltage is arranged so [22-5 and 22-16], that with the decrease of load voltage of machine the current of corrector's output $I_{\text{кор}}$ increases, and vice versa. Thus, the compounding device/equipment with the corrector of voltage regulates the excitation of machine both depending on the value of its load and depending on the value of voltage on its terminals/grippers. By the combined action of compounding and corrector is provided the maintenance of assigned load voltage of machine.

The value of the supported at the terminals/grippers of machine voltage can be changed with the aid of the adjusting ones of rheostat UR and autotransformer UAT. Knife switches or keys/wrenches of

control R-1 and R-2 serve for start and cutoff/disconnection of the compounding device/equipment and corrector of voltage.

The advantages of the compounding of excitation with electromagnetic corrector consist in the following:

1. Is provided the necessary over-excitation both with the considerable ones and with small overloadings of generator and decreases in the voltage.

2. Load voltage of generator is supported with an accuracy to ±1o/o.

3. Large simplicity and reliability as a result of absence of mechanically moving/driving parts, sparking contacts, electric ion instruments.

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In the case of short circuit in immediate proximity of machine the voltage, conducted/supplied to corrector, and the current of corrector's output prove to be close to zero and over-excitation is provided only due to compounding. Therefore for the stabilization of the multiple operation of machines additionally is installed relay

over-excitation (Fig. 22-13).

Electromechanical automatic voltage regulators have special measuring elements which depending on a change in load voltage of generator change field current either by the steady change in the resistor/resistance, connected into energizing circuit of driver or by the periodic (several times per unit time) closing/shorting of shortly similar whereas resistor/resistance. In the second case of the value of the field current of driver and coil current of rotor the machines are determined by the value of the resistor/resistance indicated and by the relative duration of the time interval during which this resistor/resistance proves to be shortened/shorted out.

In some voltage regulators are utilized both indicated of the principle of control (rheostat-vibration regulators). Similar regulators include the automatic voltage regulator of the type SN-91, which was being earlier manufactured with Kharkov Electrical Machinery Plant [22-17]. All these regulators possess essential deficiencies/lacks in comparison with the described above control system of excitation with the aid of compounding with electromagnetic corrector, recommended with TU MES of the USSR as the basic automatic control system of excitation on Soviet power plants. Therefore the device/equipment of electromechanical automatic voltage regulators here is not examined [22-16].

22-6. Start to multiple operation.

In power plants is usually installed several generators, which work in parallel with each other, and also, if station is connected with the network of power system, then in parallel and with system.

The multiple operation of generators provides: 1) an increase in the reliability of the power supply of the users; 2) an increase in the efficiency/cost-effectiveness of the operation; 3) the larger constancy of frequency and voltage during load variations.

On the power plants of the USSR apply two methods the starts of alternators of the multiple operation:

1) the method of the precise synchronization when is connected the excited generator after the achievement of the specified conditions of synchronism, and 2) the method of the self-synchronization when switch on the unexcited generator with the subsequent supply excitations in the circuit of rotor.

A necessary condition for multiple operation is the same order of alternation of phases of the operating and connected generators.

The start of generators of multiple operation by the method of precise synchronization is conducted by the observance of the

conditions:

1) the equality of the effective values of the voltages of connected and working generators (or generator and network); 2) the equality of the frequencies of the connected and working generators (or generator and network); 3) the phase coincidence of the same voltages.

The start of generator of multiple operation with another generator or network with the nonobservance at least of one of the conditions (nonsynchronous start) indicated very dangerously and can be the reason for the heavy damage of generators and disorder of multiple operation the previously worked generators. Is explained this by the fact that upon the nonsynchronous start of generators can appear the very considerable cross currents.

Let us examine the simplest diagram of the station of low voltage, given on Fig. 22-15. Let us agree that the generator G-1 works on network, and G-2 must be connected to it to multiple operation.

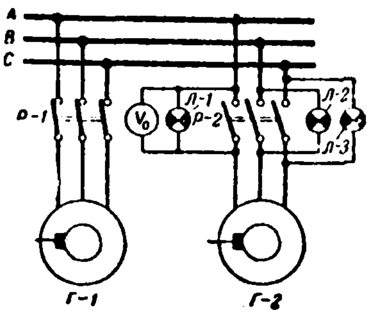

Fig. 22-15. Circuit diagram of zero voltmeter and tubes to the extinction (to dark) of syncaronizing unit.

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If we to similar/analogous phases before and after knife switch R-2 include/connect voltmeter and tubes as this is shown in the diagram, then they will be located to the voltage, equal to a geometric difference in the corresponding phase voltages of connected and working generators.

If generators work syncaronously ($f_{Г-1}=f_{Г-2}$; $U_{Г-1}=U_{Г-2}$), **then** the vectors of their phase voltages are equal in magnitude and always they coincide in phase (Fig. 22-16a; then for other two phases). In this case geometric voltage difference is equal to zero $\Delta\dot{U}_{ф}=\dot{U}_{ф\,Г-1}-\dot{U}_{ф\,Г-2}=0$, therefore the connected to similar/analogous phases tubes burn will not be, but the arrow/pointer of voltmeter

will stand on zero. If we at this moment include/connect knife switch R-2, then no cross current between generators it will arise and the connected generator will run idle.

Let us examine now the case when voltages of the generator are equal, but frequencies are not equal to ($U_{\phi r.1}=U_{\phi r.2}$, while $f_{r.1}\neq f_{r.2}$). Under this condition at each moment of time the vectors of the voltages of working and connected generators prove to be shifted certain angle δ (Fig. 22-16b). As a result of different frequencies and, consequently, also the different angular rates of rotation of the vectors of voltages ($\omega=2\pi f$), the angle δ indicated continuously changes from 0 to 180° and again to 0°. A geometric difference in phase voltages ΔU_{ϕ} also continuously is changed in limits $0\div 2U_{\phi}$.

Voltage ΔU_{ϕ} accept to call the voltage of beating. Fig. 22-17 shows the plotting of curves of the voltage of beating Δu_{ϕ} two sinusoids u_1 and u_2 of different frequencies, but with identical amplitudes. From this construction it is also evident that the amplitude of the voltage of beating is changed from 0 to $2U_{м}$. With respect to this and the arrow/pointer of the voltmeter, connected to similar/analogous phases (Fig. 22-15), will oscillate in the limits of voltages $0\div 2U_{\phi}$, but three tubes, connected on the same diagram, will simultaneously be fired and go out. From curves in Fig. 22-17 it is evident that the great throw of the pointer of voltmeter and the

greatest tension of tubes will be to moment/torque 1. At moment/torque 2 voltage of beating $\Delta u_{\Phi}=0$, tubes go out, and the arrow/pointer of voltmeter is established/installed on zero.

The greater the difference in frequencies f_{r1} and f_{r2}, the more frequent go out and are fired the tubes, the more rapid oscillates the arrow/pointer of voltmeter. On the contrary, with a small difference in frequencies the incandescence of tubes it changes slowly; so slowly oscillates the arrow/pointer of voltmeter.

Let us note that three tubes, connected to similar/analogous phases, make it possible to check the correctness of the connection of the phases of the connected generator. Upon the correct connection of phases all three tubes simultaneously light up and go out. In the installations of high voltage the tubes switch on through voltage transformers.

The inclusion of generator into the moment/torque when the vectors of the voltages of connected and working generators are out of phase, leads to that, then the generator, which rotates with certain lead/advance, sends current into another generator, which rotates with delay. Vector diagram in Fig. 22-16b exactly corresponds to the case of the inclusion of generator G-2 at the moment of vector divergence of voltages on angle δ (rotor of generator G-2

anticipated/led of angle δ the rotor of generator G-1).

At the moment of start there is voltage difference ΔU_{ϕ}. By the value of this voltage, and also by the value of the internal resistor/resistance of generators is determined the value of the cross current, which appears in generators.

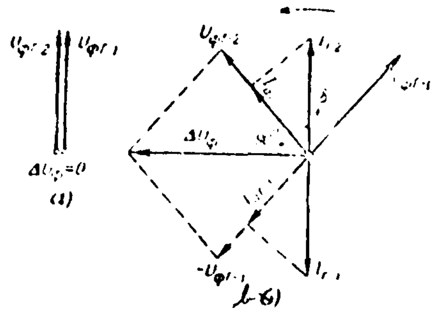

Fig. 22-16. Vector diagrams with different cases of the start of generators of multiple operation.

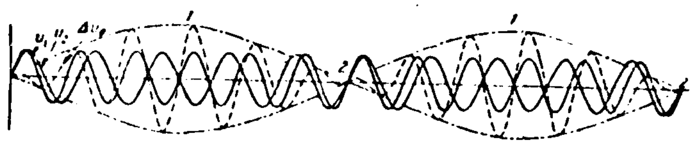

Fig. 22-17. Plotting of curves of voltage of beating Δu_{ϕ}.

[Page 360.] Under the action of voltage $\Delta U_ф$ generator G-2 (anticipating/leading) will send current into generator G-1. Since active armature resistance of alternator is small in comparison with its inductive resistor/resistance, then the current of second generator $I_{г\cdot2}$ lags behind $\Delta U_ф$ to angle, close to 90°. Respectively current in first generator $I_{г\cdot1}$ anticipates/leads $\Delta U_ф$ to the same angle.

For generator G-2 current $I_{г\cdot2}$ is the current of load, which creates braking couple, proportional to its active component $I_{аг\cdot2}$. For generator G-1 current $I_{г\cdot1}$ is current engine, which create the accelerating torque, proportional to its active component $I_{аг\cdot1}$.

However, The instantaneous appearance of a cross current creates instantaneous (in the form of jerk/impulse) a change in the speed of rotation of the aggregates/units: generator G-2 sharply brakes, but generator G-1 begins to rotate more rapidly. It is logical that in this case are possible the mechanical damages of generators and their primary motor/engines. Furthermore, large cross current creates considerable electrodynamic efforts/forces in the windings of

generators.

With the inequality of oscillator frequencies can be connected in the presence of any vector divergence of voltages $U_{\Gamma\cdot 1}$ and $U_{\Gamma\cdot 2}$. It is obvious that the greatest cross current appears upon the inclusion at moment of $\delta=180°$, when the vectors of voltages are directed contrarily $(\Delta U_{\Phi}=2U_{\Phi})$. Appearing at this moment cross current 2 times exceeds impact current during three-phase short circuit on the outputs of generator. This current represents large danger for the windings of generators.

Instruments and diagrams for the start of generators using the method of precise synchronization. The synchronization of generator consists in a change in its excitation and speed of rotation of primary motor/engine for the purpose of the achievement of conditions indicated above for multiple operation.

Equalities voltages attain by current control of the excitation of the synchronized generator. Equality voltages is monitored on two voltmeters one of which shows lcad voltage of the synchronized generator, and by the second - a voltage on the collecting mains of station or the terminals/grippers of the working generator.

Equalities frequencies attain by controlling the speed of

rotation of primary motor/engine of the synchronized generator. For this directly from control board with the aid of electrical remote regulator is changed the intake of steam into steam turbine or water into hydraulic turbine. With the impossibility to remotely change steam admission or water into primary motor/engine is utilized the engineroom telegraph with the aid of which are supplied the signals "to add" and "to diminish" into machine room. Equality frequencies is monitored on two frequency meters one of which shows the frequency of the synchronized generator, and by the second - frequency on the collecting mains of station (working generator).

Phase displacement of the voltages of synchronized and working generators (or network/grid) is monitored with the aid of the various kinds of the phasemeters as which it is possible to utilize incandescent lamps, zero voltmeters and synchroscopes. According to these instruments is installed the moment/torque, when the voltages of synchronized and working generators (or network/grid) coincide in phase.

Synchronization only with the aid of some tubes, connected to similar/analogous phases, i.e., to extinction at the moment of the synchronism (start to dark - see Fig. 22-15), it is very inadequate as a result of the impossibility to accurately trap the moment/torque of synchronism.

Is considerably more precise synchronization with the aid of the zero voltmeter, connected to similar/analogous phases (V_0 in Fig. 22-15): generator is connected in the moment/torque when the arrow/pointer of zero voltmeter slowly approaches zero. A deficiency/lack in the synchronization on zero voltmeter is the fact that its arrow/pointer is deflected to one and the same side regardless of the fact, does rotate the synchronized generator more rapid or slower. In other words, zero voltmeter does not give indication about how it is necessary to regulate the speed of rotation of generator.

For the purpose of the facilitation of the control of machines with synchronization and the accelerations of the process of synchronization apply the synchroscopes which not only make it possible to trap the phase coincidence of working and synchronized generators, but also show, does rotate the synchronized generator more rapid or slower than the worker.

Are applied electromagnetic and ferrodynamic synchroscopes.

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In the form of an example Fig. 22-18 shows the principle of the device/equipment of electromagnetic synchroscope. Synchroscope consists of three securely fastened coils, made from a large number of turns of thin covered wire. Coils 5 and 6 are arranged/located at the angle to each other and surround central coil 1, within which is placed z-shaped steel core 2, attached together with indicating arrow/pointer 3 on axis 4. Core, arrow/pointer and axis form the moving element of the instrument.

Coil 1 they connect to the voltage of the working generator (or network/grid), and coils 5 and 6 - to the voltage of synchronized generator. Upon the start of synchroscope the currents, flowing through its coils 1, 5 and 6, create three variable/alternating magnetic fluxes, not cophasal and shifted in space one with respect to another. These three flows store/add up and is created certain resulting magnetic flux. Z-shaped core always is established/installed along the axis of the resulting magnetic flux.

If generators work synchronously, then the axis of the net flux occupies the completely specific position and the arrow/pointer of synchroscope is established/installed vertically (on vertical feature). With equality frequencies, but noncoincidence of phases the arrow/pointer is deflected to certain angle to that or other side. If frequencies are not equal, then the axis of the net flux always is

displaced (changes phase displacement) and the arrow/pointer of synchroscope rotates in that or other side.

Rotation or displacement of arrow/pointer to the right (clockwise) attests to the fact that the synchronized generator rotates more rapid than the worker and vice versa. The switch of the synchronized generator should be switched on in that moment/torque, when the arrow/pointer of synchroscope slowly approaches the vertical feature.

Until generator is connected to multiple operation with other generators it it cannot long work synchronously with them (changes the speed of rotation of primary motor/engine). Therefore during synchronization it is not possible to attain that the arrow/pointer of synchroscope (zero voltmeter) prolongedly would stand on vertical feature (on zero).

Regulating the speed of rotation of the synchronized generator they attain, that the arrow/pointer of synchroscope slowly would rotate in the direction of rotation of the hour hand (but the arrow/pointer of zero voltmeter completed slow oscillations). If they synchronize the generator of low voltage, included by knife switch or automaton directly on the distributing frame, then after waiting, when the arrow/pointer of synchroscope slowly approaches the vertical

feature (but the arrow/pointer of zero voltmeter - to zero), is connected generator.

During remote control of generator switch from control board, as this usually is in the installations of high voltage, one should consider that from the moment/torque of closing/shorting on the control board of the circuit of the start of drive to the moment/torque of the beginning of the contact of the contacts of switch is passed the time, measured by the tenths of second. Therefore upon remote switching should be closed the circuit of start with certain lead/advance, i.e., it is earlier than the arrow/pointer of synchroscope it will reach the vertical feature (arrow/pointer of voltmeter to zero). The necessary lead/advance (lead angle) depends on a difference in the frequencies (speed of the motion of arrow/pointer) and the time of action of switch and its drive. The more rapid moves the arrow/pointer and the greater the time of action of drive and of switch, the more must be lead angle upon remote switching.

Inadmissible to switch on generator when the arrow/pointer of synchroscope (zero voltmeter) is moved from vertical feature (from zero), stopped at it (on zero) or greatly rapidly it approaches it (to zero).

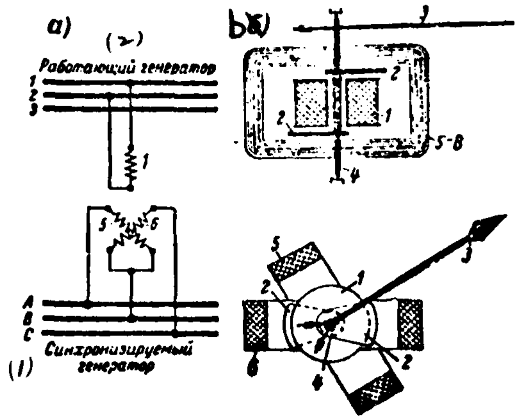

Fig. 22-18. Electromagnetic synchroscope. a - circuit diagram; b - schematic of device/equipment.

Key: (1). Synchronized generator. (2). Working generator.

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Fig. 22-19 in the form of an example gives fundamental synchronizing circuit for a station of high voltage with two systems of collecting mains. On diagram is provided the possibility of the synchronization of any of the generators G-1 and G-2 of collecting mains, and also the synchronization of two sets of busbars between themselves with their connection to multiple operation by bus-connecting switch ShV. Voltage from the synchronized parts of the installation it is fed/conducted to the instruments of

synchronization through the keys/wrenches of synchronization KS-1, KS-2 and of KS-3 and busbar of synchronization ShS. In order to ensure the correct synchronization of generator with that set of busbars of which it is assumed it to include/connect, voltage from voltage transformers TN-1 and TN-2 on collecting mains is fed/conducted to the keys/wrenches of synchronization through the blocking contacts of busbar/tire disconnectors.

For synchronization is provided the column of synchronization, which consists of two voltmeters, two frequency meters and synchroscope S.

Before the start of generator of multiple operation is checked the state of its primary circuit and they connect busbar disconnector to that set of busbars to which they intend to include/connect generator. Then aggregate/unit turn/run up to normal speed rotations and excite to the voltage, equal to voltage on the busbars of the station (being guided by readings of the voltmeter of generator). After this they close the key/wrench of synchronization KS of the synchronized generator and thereby is supplied voltage on the busbars of synchronization ShS. Voltage from generator is supplied to the busbars of synchronization $a_г$, $b_ш$ and $c_г$, and from collecting mains - to busbars $a_ш$ and $b_ш$.

Being guided by readings of voltmeters and frequency meters on the column of synchronization, more accurately are regulated voltage and frequency of the synchronized generator. Then by the auxiliary key/wrench K is connected synchroscope S and after the necessary control of aggregate/unit they are connected it the multiple operation, as noted above.

After the start of generator is translated to it the part of the active and reactive load from the working generators.

If the collecting mains of station are subdivided by automatic switch, then additionally is provided for the synchronization of sections with the start of sectionalizing switch. At the stations, connected with the network/grid of the power system, is necessary the synchronization of station with system.

From all that has been previously stated, it follows that the process of the synchronization of generators is sufficiently complex and the moment/torque of their start must be selected accurately. Nonsynchronous start can lead to the damage of aggregate/unit or the disruption of multiple operation the previously worked generators.

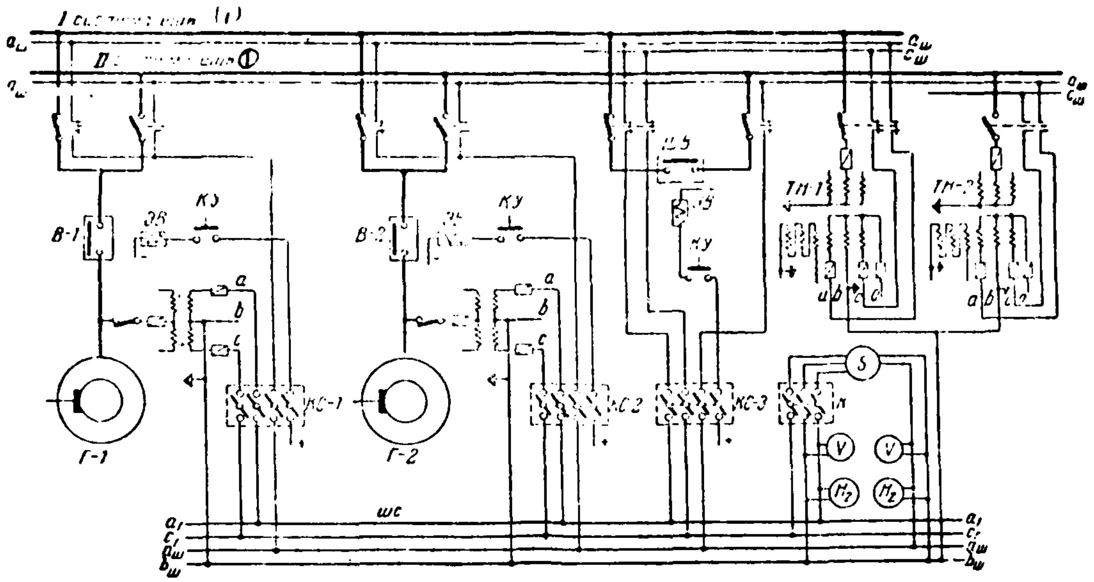

Fig. 22-19. Fundamental synchronizing circuit for a power plant.

Key: (1). set of busbars.

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Precise synchronization is especially hindered/hampered with emergencies in the system when current frequency is variable.

For the purpose the prevention of the nonsynchronous starts of generators provides for the special relays, which warn erroneous starts with synchronization. In certain cases apply the automatic synchronizers, which realize both the control the frequencies and

voltages and inclusion of generator switch at the most favorable moment of synchronization [L. 22-15 and 22-16].

Start of generators of parallel work by the method of self-synchronization. In recent years at our stations use extensively fundamentally new method the starts of generators of multiple operation - the method of self-synchronization. Using this method the unexcited generator, which rotates with speed, a little different from synchronous, is connected in network/grid and simultaneously is supplied excitation into the circuit of rotor, after which the generator itself is pulled into synchronism [L. 22-18 and 22-19].

At the moment of the start of generator residual load voltage of its stator must not exceed $0{,}2U_{\text{г.ном}}$, and a difference in the frequencies of the network/grid and generator must not be more than 1.5 Hz (speed of rotation of generator must not differ from synchronous more than by ±3o/o). Under emergency conditions it is possible to switch on generator, also, with somewhat larger difference in the frequencies (it is established/installed for each generator in dependence on its type and power of power system).

Using this method the starting process of generators of multiple operation following:

1. Via cutoff/disconnection AGP preliminarily extinguish magnetic field machines and is connected its device/equipment of automatic field control. By shunt rheostat in energizing circuit of driver must be located in normal operating position, and adjusting rheostat ARV - in the position, which corresponds to 40-60o/o of nominal load of generator [1. 22-19]. The device/equipment of automatic field control can be also switched on simultaneously with the inclusion of generator into network/grid.

If in generator ARV no then presets by shunt rheostat in energizing circuit of driver in the position, indicated above for an adjusting rheostat ARV.

2. With the aid of primary motor/engine turn/run up unexcited generator to speed rotations, close to synchronous, in voltmeter in circuit of stator they are convinced that voltage on its terminals/grippers is equal residual/remanent, and upon reaching of difference indicated above in frequencies of network/grid and generator is connected generator in network/grid.

3. After inclusion of generator into network/grid immediately is supplied excitation by start AGP. Field regulator automatically increases the excitation of generator, and the latter smoothly enters into synchronism. It is expedient to automate start AGP by the

closing a circuit of its electromagnet by the blocking contacts of the drive of switch.

If on generator ARV no, then immediate after the start of generator is installed the required excitation by hand with the aid of shunt rheostat.

4. They load generator.

At the moment of the inclusion into the network/grid of the unexcited generator it consumes from network/grid the considerable inductive current, which creates on stator the rotating magnetic field which induces emf in the excitation winding of generator. If the latter is gotten soaked, then induced in it emf can be very considerable and dangerous for its insulation. Therefore upon the inclusion of generator into network/grid its excitation winding must be locked to certain effective resistance by value which is determined overvoltage on excitation winding at the moment of the inclusion of generator into network/grid.

If generator is equipped with old type AGP (Fig. 22-9 and 22-10), then via cutoff/disconnection AGP they preliminarily close its excitation winding to discharge resistor; in this case residual load voltage of stator, caused by remanent magnetism of machine, does

not exceed 0.2 $U_{\text{г.ном}}$ and usually are approximately 100-250 V.

If generator is equipped with new type AGP with arc-suppression grating, for example type AGP-1 (Fig. 22-12), then it is preliminarily necessary to include/connect AGP-1, after connecting the excitation winding of generator to driver, and to disconnect contactor $K_{\text{н}}$, after introducing thereby discharge resistor to 4 into energizing circuit of driver.

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It is obvious that in this case residual load voltage of the stator of generator will be considerably more, rather than with old type AGP, since its value will be determined no longer only remanent magnetism of machine, but also by small field current as a result of the fact that on the terminals/grippers of driver is retained certain voltage. The latter is caused by the residual/remanent excitation of driver, since resistor/resistance to 4 although decreases the field current of driver, not to zero.

If caused by the reasons indicated residual load voltage of the stator of generator does not exceed permissible maximum value $0.2U_{\text{г.ном}}$ (see above), then generator can be switched on in network/grid by the method of self-synchronization.

However, powerful/thick generators with the connected driver with the extinguished field usually have residual load voltage of stator more $0{,}2\,U_{\text{г.ном.}}$ in consequence of which with the fulfillment of energizing circuit on diagram in Fig. 22-12 them it is not possible to switch on by the method of self-synchronization. For these generators is applied driving circuit, supplemented special by back-out resistor ShS with the contactor of self-synchronization ~~KCC~~ KSS (diagram in Fig. 22-20, which should be considered as the supplementary to diagram in Fig. 22-12). With the normal work of generator the contacts of contactor KSS are extended and the resistor/resistance of ShS is disconnected.

Relays R with time element to closing of contacts (during de-energizing of its coil) and blocking contacts 8 and 9 serve for control of contactor KSS. During damage the generator and cutoffs/disconnections AGP-1 blocking contacts 8 are broken, but blocking contacts 9 are closed. The first disrupt the circuit of the coil of relay R whose contacts are closed, but with certain time element during which AGP-1 manages to disconnect the excitation winding of generator, i.e., to extinguish its field. Through locked blocking contacts 9 and contacts of relay R, is closed the circuit of the electromagnet of contactor ~~KCC~~ KSS and the latter closes the circuit

of the resistor/resistance of ShS, which shunts excitation winding of 1 generators. Generator prepares for start by the method of self-synchronization. The value of the resistor/resistance of ShS is 2-3 times more than field resistance in hot state.

Upon start AGP-1 blocking contacts 9 disrupt the circuit of electromagnet KSS and the latter automatically disconnects the resistor/resistance ShS.

On the generators of small power there can not be AGP. Then to the development of generator is introduced into energizing circuit of driver all the resistor/resistance of shunt rheostat.

As noted above, at the moment of the inclusion into the network/grid of the unexcited generator its rotor can rotate at velocity less or larger synchronous. If the speed of rotation of rotor is lower than the synchronous, then the rotating magnetic flux of stator, created with the consumed from network/grid inductive current, induces coil currents of rotor, locked to discharge resistor, in damper winding and in the steel mass of rotor. Interaction of these currents with the rotating magnetic flux of stator creates asynchronous turning moment (as in asynchronous electric motors), that attempt to decrease the slip of rotor and to draw it in synchronism.

But if the speed of rotation of rotor is more than synchronous, then generator begins to give up in network/grid the active power (it works as induction generator), as a result of which is created braking couple, and the speed of rotation of rotor decreases, approaching synchronous.

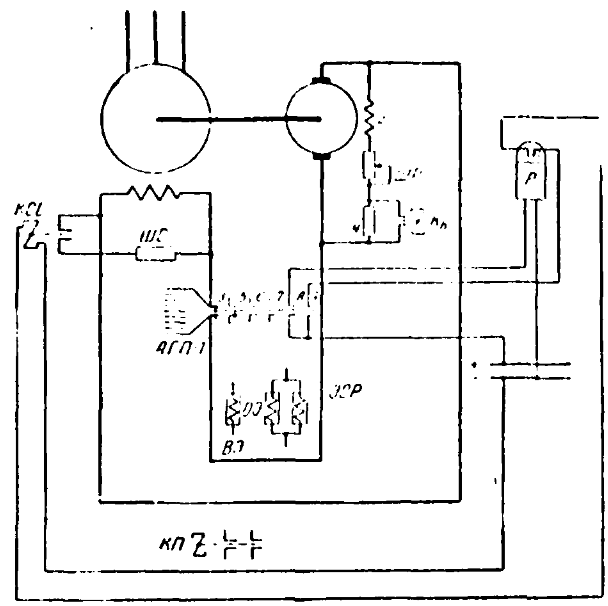

Fig. 22-20. Circuit diagram of back-out resistor, necessary for the self-synchronization of the powerful/thick machines, equipped with the automatic field dampers with arc-suppression gratings.

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At the moment of the connection of the rotor winding to driver and with an increase in the field current appears considerable in value synchronous moment/torque, and generator smoothly it enters into synchronism. The transient process of self-synchronization lasts, as a rule, not more than 1-2 s.

Upon the inclusion of generator using the method of self-synchronization in the windings of stator-rotor unit appear the currents of the unsteady process of the same character as during short circuit, since the inclusion into the network/grid of the unexcited generator is with respect to network/grid three-phase closing/shorting after inductive reactance of the included generator. Due to external resisting (transformer, electric power line, reactor, etc.) these currents are somewhat less than the currents of three-phase short circuit on the terminals/grippers of generator and therefore for it they are not dangerous. In the worst case, upon the start of generator of the busbars of the system of unlimited power $(x_c = 0)$, the current spike at the moment of start is equal to impact current during three-phase short circuit on the terminals/grippers of generator.

Let us note that the cross currents in the case of the erroneous start of generators by the method of precise synchronization can considerably exceed currents upon start by the method of self-synchronization. It was previously indicated that with the method of precise synchronization at the most unfavorable moment of the inclusion the current spike can 2 times exceed impact current during three-phase short circuit on the terminals/grippers of

generator. Furthermore, the cross currents, which appear upon start by the method of precise synchronization, cause, as noted earlier, considerable mechanical stresses in aggregate/unit, while currents upon start by the method of self-synchronization are almost purely inductive and they do not cause any considerable mechanical stresses in aggregate/unit.

The start of generator by the method of self-synchronization is accompanied by certain decrease in the voltage on the busbars of station at the moment of start. However, taking into account the presence on the generators of the devices/equipment of over-excitation and the short duration of transient process upon the inclusion into the network/grid of the unexcited generator, this decrease in the voltage does not have vital importance for a power system and users of electric power.

If generator is connected to the collecting mains through the step-up transformer, then the latter substantially limits current upon start and decrease in the voltage on collecting mains.

On the basis of the scientific research works conducted and analysis of operating experience it is at present recommended the method of self-synchronization to apply as the fundamental method of start to the multiple operation of all synchronous generators in

power to 3 MW inclusively, all hydraulic generators and synchronous condensers with starting electric motors independent of their power and diagram of the connection to collecting mains and all turbogenerators which work in block with the step-up transformers.

Turbogenerators in power more than 3 MW, which work directly to the collecting mains of generator voltage, can be switched on to multiple operation by the method of self-synchronization when periodic component/term of transient current upon the start of generator does not exceed value of 3.5 $U_{г.ном}$. With high currents at the moment of start one should switch on generators by the method of precise automatic synchronization.

In emergency mode should be all generators switched on the method of self-synchronization.

The value of periodic of component/term of the current, which appears upon the start of generator by the method of self-synchronization, it is possible to determine by the formula

$$I' = \frac{U}{\sqrt{3}(x'_d + x_c)}, \qquad (22\text{-}3)$$

where U - an interphase voltage of the installation;

x'_d — transient inductive reactance of the generator;

x_c — resisting of system to the terminals/grippers of generator.

The method of self-synchronization can be applied, as this appears from that presented, only upon the start of the unloaded generators. Start to the multiple operation of two loaded generators, two parts of the station, working nonsynchronously and the like, possibly only by the method of precise synchronization.

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The major advantages of the method of the self-synchronization: 1) simplicity of the process/operations, which make it possible faultlessly to switch on generator and it is easy to automate the process of the start; 2) the speed of the start; 3) the possibility of the inclusion under the emergency conditions for work during the strong oscillations of voltage and frequency in system.

The method of self-synchronization made it possible to realize start to the multiple operation of generators on those small power plants where earlier as a result of absence on primary motor/engines of speed regulators it was generally impossible or very difficultly

start to multiple operation the method of precise synchronization.

Fundamental difficulty in conducting of self-synchronization consists in the establishment of a difference in the frequencies of the connected generator and network/grid. Are applied the special devices/equipment, which make it possible to determine the frequency of the connected generator with the use of its residual voltage.

Are developed and widely are applied in practice different of devices/equipment and diagram of manual, semiautomatic and automatic [22-18 and 22-19].

In conclusion let us point out that the tests, carried out TsNIEL MES and some power systems, demonstrated the possibility of the nonsynchronous start of the emergency disconnected electric power lines of the sufficiently large cross sections, connecting power plants or parts of the power system. The asynchronous automatic resets of such lines in the majority of the cases prove to be successful: after several cycles of the nonsynchronous course of stations or part of the system they are pulled into synchronism. Possibly also the immediate conversely start of such lines without checking of synchronism and by hand.

The start of lines without checking of synchronism is admissible [L. 22-20] when the relation of the current of the nonsynchronous

start, which appears upon start with the angle of divergence of the vectors of emf of 180°, to the rated current of generator does not exceed for the turbogenerators or value of 5, but for hydraulic generators 3. During the determination of the current of the nonsynchronous inclusion one should generators to introduce into replacement scheme their ultratransitory resisting x''_d and accept that emf of generators coincide in phase and are equal to $1.05 U_{г.ном}$.

22-7. Diagrams of launching/starting the synchronous condensers.

The synchronous condensers serve for the generation of the reactive power, necessary for the work of users and network/grid of electrical system.

The synchronous condensers install mainly in regional substations and considerably less frequently on the substations of local importance. In industrial enterprises as the synchronous condensers fairly often are utilized the overdriven synchronous electric motors, which carry mechanical load.

Soviet plants manufacture the synchronous condensers to nominal power with the anticipating/leading current to 75,000 kVA and to nominal voltage to 11 kV inclusively. Structurally/constructurally

synchronous condensers, their excitation, cooling, etc. are performed similarly to alternators. The compensators of large power are made with the hydrogen cooling (see § 22-2).

On the reducing substations the synchronous condensers connect to the collecting mains of the corresponding secondary voltage.

The most widely used methods of launching/starting the synchronous condensers they are: 1) the asynchronous launching/starting of straight line and 2) asynchronous reactor starting.

In both cases the synchronous condenser they start as asynchronous squirrel-cage motor. For the creation of starting torque of the compensator rotor it has specially carried out damper winding, placed on its band caps.

During straight/direct launching/starting compensator they connect up the collecting mains of the substation through the switch and the busbar/tire disconnector (Fig. 22-21a).

Start up procedure of compensator with driver on one shaft:

1. The handle of shunt rheostat is set in the position, which corresponds to idling, automatic field regulator is disconnected.

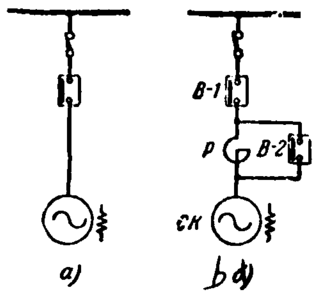

Fig. 22-21. Schematic diagrams of launching/starting the synchronous condensers. a) the asynchronous launching/starting of the straight line; b) asynchronous reactor starting.

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2. Is connected automatic field damper, than excitation winding of compensator they close to armature of driver.

3. Is connected switch; compensator is turned/run up as induction motor (asynchronous torque is created by currents in damper winding of rotor) and after certain time it reaches full/total/complete asynchronous rotational speed; since rotor winding before launching/starting was connected to driver, then in proportion to development of compensator coil current of rotor increases (it increases excitation), appears synchronous moment/torque and compensator smoothly it is pulled into synchronism.

4. To compensator they give excitation, which corresponds to load mode/conditions.

5. Switch on automatic field regulator and install by it required mode/conditions works of compensator.

Advantages of the straight/direct launching/starting: simplicity and small number of starting switches (one). Shortcomings: at the moment of launching/starting the compensator of considerable power in power line occurs large current surge, and on the collecting mains of substation - considerable decrease in the voltage, which deranges of the connected to them users. In connection with this straight/direct launching/starting in the majority of the cases is applied for the compensators of comparatively small power.

The schematic diagram of launching/starting the synchronous condenser through the reactor is given in Fig. 22-21 b, Compensator
SK
CK they supply with two switches: main V-1 and auxiliary V-2, that shunt reactor with the normal operation of compensator. Reactor values are selected so that at the moment of the launching/starting when compensator and reactor are connected in series, but shunting switch V-2 is disconnected, voltage on the busbars of substation descended not more than to 80-85o/o of normal, but the voltage, applied to the terminals/grippers of compensator, composed 30-65o/o

of nominal value.

Before launching/starting switches V-1 and V-2 are disconnected. Start up procedure:

Points/items 1 and 2 the same as during straight/direct launching/starting.

3. Is connected switch V-1; in this case to compensator is fed/conducted low voltage, which composes (depending on reactor values) 30-65o/o of nominal, and it begins to turn as induction motor; when rotational speed proves to be close to synchronous, compensator is pulled into synchronism.

4. Is connected switch V-2 how they shunt reactor and feed/conduct to compensator total voltage.

Points/items 5 and 6 - the same as points/items 4 and 5 during straight/direct launching/starting.

Advantages of reactor starting: simplicity and evenness of launching/starting. The latter is explained by a gradual increase in load voltage of compensator with an increase in the rotational speed, which occurs because of the decrease of the starting current of

compensator and as consequence to the decrease of a voltage drop in reactor.

Asynchronous reactor starting at present has preferred use/application.

In both cases launching/starting the synchronous condenser can be automated.

Chapter twenty-three.

POWER TRANSFORMERS.

23-1. Fundamental characteristics.

Types of transformers. On electrical stations and substations apply those reducing and raising, two- and triple-wound, three-phase and single-phase power transformers.

Three-phase transformers are cheaper than groups of three single-phases transformer of the same power; it is simpler and is cheaper also their operation. Therefore in all cases when this is possible, are applied three-phase transformers. Groups of single-phases transformer apply only with impossibility the productions of the three-phase transformers of the necessary power or during transport limitations (for example, in mountain localities).

Soviet plants manufacture transformers to all voltages to 500 kV inclusively and nominal power up to several hundred thousand kilo-volt-amperes (see appendix P-4).

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The transformers of small and average/mean power (to 7500 kVA inclusively) make with oil-immersed natural cooler, and the large power (10,000 kVA it is above) - with natural oil and forced ventilation (with the blowing of tank by fans). Sometimes the transformers of large power fulfill with oil-water or oil-air cooling, i.e., with the forced circulation oils and its water cooling or with the forced circulation of oil through air coolers. Soviet plants, furthermore, manufacture transformers in power to 750 kVA and by voltage to 13.8 kV connected with natural air cooler, called "dry". They are intended for a work only in the closed locations.

Air-immerseds transformer, which are flame-resistant, are used extensively in the built-in substations, for example in the installations of its own needs of electrical stations and substations, on the intrashop transformer substations of industrial enterprises, etc.

Nominal voltages of the windings of transformers. The nominal primary voltage of transformer is called the interphase voltage which must be conducted to its primary winding in order on the terminals/grippers of extended secondary winding to obtain nominal secondary voltage.

Nominal secondary voltage is called the interphase voltage, obtained on the terminals/grippers of secondary winding of transformer with its idling and supply to the terminals/grippers of the primary winding of nominal primary voltage.

During the work of transformer under load and supply to the terminals/grippers of its primary winding of nominal voltage, load voltage of secondary winding is lower than the nominal on magnitude of losses voltage in transformer.

The standard nominal voltages of transformers are given in chapter 3.

By the nominal voltages of windings is determined the transformation ratio of transformer $k_т$. by which they understand the relation of the nominal voltages: the windings of the highest VN and lowest NNvoltages in double wound transformer and each pair of windings VN and NN, VN and SN (medium voltage), SN and NN - in triple-wound transformer. For example, the transformation ratio of the three-phase double wound step-down transformer in nominal power 10 MVA and nominal voltages of windings $U_{ном\ ВН}=35$ kV and $U_{ном\ НН}=6.6$ kV is equal to

$$k_т=\frac{U_{ном\ ВН}}{U_{ном\ НН}}=\frac{35}{6,6}=5,3.$$

Permissible heating temperatures. In process the work of winding and steel core of transformer are heated. The metallic parts of the transformer can without damage prolonged time maintain/withstand comparatively high heating temperatures. The insulation of windings on reliability of which, first of all, depends the reliability of the work of transformer, during heating gradually is abraded, it ages. Ageing insulation is characterized by the decrease of its elasticity and mechanical strength. The strongly comprised insulation becomes this inelastic and brittle that under the effect of vibrations and electrodynamic efforts/forces, which occur with the work of transformer it begins to burst and to break, i.e., mechanically to be damaged. The consequence of this can be the electrical breakdown of insulation and the damage of transformer. The time, during which the insulation is abraded so, that it due to its physical state becomes already unsuitable to further work, it depends on the temperature of its heating. With an increase in the latter, other conditions being equal, the service life of transformer decreases.

For the transformers of domestic manufacture is accepted this permissible temperature of heating the insulation of windings, during which is provided the service life of the transformers of 20-25

years.

According to GOST 401-41 for the transformers, adjusted in the localities where the maximum temperature of air ϑ_0 reaches 35°C, temperature excess of windings τ above the temperature of air must not exceed 70°C. For Soviet transformers temperature excess of windings, equal to 70°C, corresponds to their nominal load in ϑ_0=35°C. Therefore the greatest permissible temperature of heating the windings of transformer composes $\vartheta=\vartheta_0+\tau=35+70=105$°C.

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If in the process of operating the transformer the temperature of heating its windings is constantly supported with the equal to 105°C, then, as show the investigations of manufacturing plants, the service life of transformer will comprise less than 2 years.

However, with the nominal load of transformer temperature of ϑ=105°C will be constant only in such a case, when by constant it will be ϑ_0=35°C. In actuality the temperature of surrounding air is never constant, but it changes both in the course of twenty-four hours and during year. For example, in the central band of the USSR where they are arranged/located Moscow, Leningrad, Sverdlovsk, annual oscillations of the temperature of air in the majority of the cases

they lie/rest within limits of $\pm 35°C$. In view of this the temperature of heating the windings of transformer in the course of twenty-four hours, and also during year changes within the limits from 105°C to certain smaller value. In this case the service life of transformer, naturally, is lengthened.

Therefore the indicated above greatest temperature of windings by 105°C should be understood as the maximum heating temperature, permitted for the safe work of transformer several hours in a 24 hour period during those comparatively a few days when the temperature of surrounding air reaches maximum (35°C).

The wear of insulation and the service life of transformer depend also on the average annual temperature of the locality where the transformer is established/installed. With an increase in the average annual temperature of air the service life of transformer decreases. To what extent are different they can be the average annual temperatures of air, evidently from the following. In the moderate climate where, for example, they are arranged/located Moscow, Leningrad, Sverdlovsk, Novorossisk, average annual temperature of air $\vartheta_{0cp} \approx 5°C$, while in regions of Baku, Tbilisi, Yerevan, Tashkent $\vartheta_{0cp} \approx 15°C$; in region of Arkhangelsk $\vartheta_{0cp} \approx 0°C$ and so forth.

GOST 401-41 to power transformers installs the temperatures of their heating taking into account daily variations of the temperature of air, and also average annual temperature of locality. In this case is introduced the concept the "nominal temperature conditions of the cooling medium", by which for the transformers, established/installed on the open air and having the natural oil or natural oil and forced ventilation, should be understood the logically changing temperature of air coolant in the locality where its maximum value is equal to 35°C, and average annual of +5°C. GOST 401-41 also installs great temperature excess of the upper layers of oil $\tau_м$ (in the cover/cap of transformer) above the temperature of surrounding air, which must not exceed by 60°C. At temperature of surrounding air of ϑ_0=35°C this corresponds to the greatest observed (on thermometer) temperature of oil $\vartheta_м = \tau_м + \vartheta_0 \approx 60 + 35 = 95°C,$ with which the temperature of heating windings it is ϑ=105°C. The latter, as noted above, is the maximally permissible temperature of heating the windings of transformer. Therefore $\vartheta_м = 95°C$ is the maximally permissible temperature of oil of transformer.

The nominal power of transformer is called the power to which the transformer, established/installed in the open air, can be continuously loaded during entire its service life under the nominal temperature conditions of the cooling medium, i.e., with maximum and average annual the logically changing temperatures of air coolant,

equal to with respect 35 and 5°C. In this case the transformer has the normal service life (on the order of 20-25 years), limited to the wear of the insulation of windings. The nominal power of transformer is measured in kilowatt-amperes and it is indicated on its certified/rating table.

If the temperature conditions of the cooling medium different from nominal ones, then for guaranteeing the normal service life of transformer its nominal power must be changed, i.e., the power of transformer must be re-marked. So, if in the site of installation of transformer $\vartheta_{0\,cp} \neq 5°C$, then to transformer must be appropriated the nominal power, determined according to the formula:

$$S'_{ном} = S_{ном}\left(1 + \frac{5 - \vartheta_{0\,cp}}{100}\right). \qquad (23\text{-}1)$$

where $S_{ном}$ — nominal power of this transformer on certificate.

When the temperature of air ϑ_0 is higher than 35°C (but not higher than 45°C), the load of transformer must be lowered on (ϑ_0-35) o/o in comparison with nominal power.

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Besides installation in the open air, transformers fairly often they place in the closed unheated areas - chambers/cameras. In this

case in chambers/cameras in the majority of the cases is provided for the natural ventilation, realized with the aid of special openings/apertures in the lower and upper parts of the chamber/camera. The sections of input and outlets and the height of the location of the latter receive such that the difference between the temperatures of the entering and emerging air coolant would be approximately 15°C. In spite of ventilation, conditions coolings of the transformers, established/installed in chambers/cameras, prove to be worse than for those established/installed in the open air. So, under the nominal temperature conditions of surrounding air and difference in the temperatures entering the chamber/camera and emerging from it air of approximately 15°C average annual temperature of air coolant in the chamber/camera of transformer is obtained equal not to 5°C, but are approximately/exemplarily on 8°C above, i.e., about 13°C. It is logical that in this case the wear of the insulation of the windings of transformers, established/installed in the closed locations, with the identical graphs/curves of load with the transformers, established/installed in the open air, is obtained large, but the service life of transformers - smaller.

In the triple-wound transformers of the winding of different voltages have identical or different nominal power (table P-4). In connection with this for the nominal power of triple-wound transformer, indicated on certified/rating table, accept power its

primary windings.

Example 23-1. Transformer with a nominal power of $S_{ном}=31{,}5$ MVA has relationship/ratio of power of windings, equal to 100:100:67o/o. The power of each of the windings comprises: windings VN and SN $S_{BH}=S_{CH}=$ 31.5 MVA, windings $HH-S_{HH}=31{,}5\frac{67}{100}=21{,}1$ MVA.

By the rated currents of primary ($I_{1\,ном}$) and secondary ($I_{2\,ном}$) of the windings of transformer are called the currents, determined on nominal power and nominal voltages of the corresponding windings of transformer. For example, for the three-phase double wound step-down transformer the transformation ratio of which was determined above, the rated currents of windings comprise:

$$I_{1\,ном}=\frac{10\,000}{\sqrt{3}\cdot 35}=165\ a;\quad I_{2\,ном}=\frac{10\,000}{\sqrt{3}\cdot 6{,}6}=877\ a.$$

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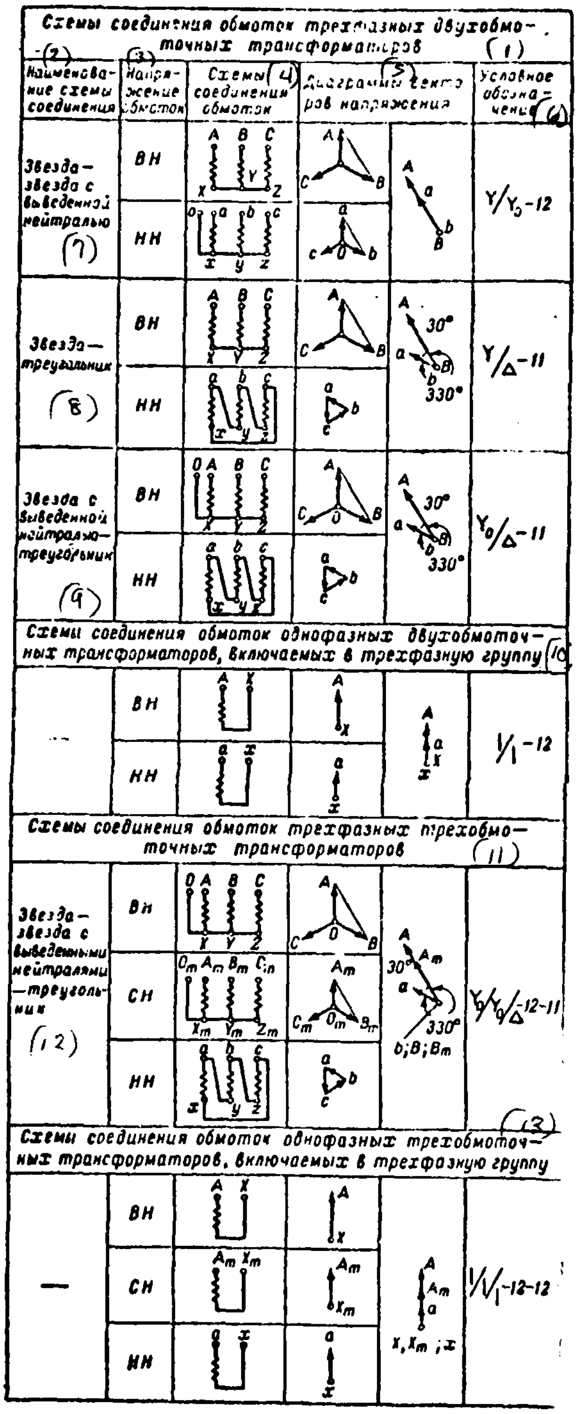

Fig. 23-1. The most widely used diagrams of connection of the windings of power transformers, diagram of the vectors of their voltages and the conventional designations.

Key: (1). Diagrams of connection of the windings of three-phase double wound transformers. (2). Designation of connection diagram. (3). Voltage of windings. (4). Diagrams of connection of windings. (5). Diagrams of vectors of voltage. (6). conventional designations. (7). Star-star with brought out neutral. (8). Star-triangle. (9). Star with that brought out neutral triangle. (10). Diagrams of connection of windings of single-phase double wound transformers included in three-phase group. (11). Diagrams of connection of windings three-phase of triple-wound transformers. (12). Star-star with those brought out by neutral-triangle. (13). Diagrams of connection of windings of single-phase triple-wound transformers, included in three-phase group.

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Under nominal load is understood the load, equal to rated current, which the transformer, established/installed in the open air in the locality where the maximum and average annual values of the logically changing temperature of air coolant are equal to with respect 35 and 5°C, it can bear continuously. In this case the service life of transformer is approximately 20-25 years.

Let us note that in operation the load of transformer usually is monitored on current with the aid of ammeter.

Diagrams and group of the connections of windings and their use/application. Most widely used and standardized GOST of 401-41 diagrams and group of the connections of the windings of transformers are given in Fig. 23-1.

In the conventional designations of double wound transformers the first sign is related to the winding VN, to the second - to the winding NN, index 0 indicates the conclusion/output of neutral, and number 11 or 12 - a group of the connection of windings (the angular displacement of the vectors of the interphase voltages of winding NN with respect to the vectors of the interphase voltages of the winding VN).

Three-phase transformers with the windings, connected on diagram Y/Y_0, manufacture on the nominal voltage of low-voltage winding by 230/133 or 400/230 V (for four-wire networks/grids). In all remaining cases three-phase transformers are manufactured with the windings, connected on diagrams Y/Δ-11 or Y_0/Δ-11. The latter of these connections is applied when the neutral of the high-voltage winding of transformer must be grounded.

In the conventional designations of three-phase triple-wound transformer the first sign is related to the winding VN, to the second - to winding SN, the third - to the winding NN, indices 0 indicate the conclusion/output of neutrals, number 12 - a group of the connection of the winding VN with respect to the winding SN, and number 11 - a group of the connection of the windings VN and SN with respect to the winding NN.

The windings of single-phases transformer, included into three-phase groups, connect on diagrams Y/Δ-11, Y_0/Δ-11 or $Y_0/Y_0/\Delta$-12-11. Let us note that for its own needs of power plants in certain cases are applied both other diagrams and groups of the connections of the windings of the transformers (see Vol. 2, chapter 6).

23-2. Permissible overloadings of transformers.

In operation the load of transformer, as a rule, does not occur its permanent and equal nominal power, but it changes both in the course of twenty-four hours and in dependence on season. In this case during the significant part of the days the load of transformer is usually less than the nominal.

In connection with this temperature excess of windings τ above

the temperature of air coolant does not remain constant and equal to 70°C, but it oscillates in limits from 70°C to certain smaller value. This leads to the decrease of the wear of the insulation of windings and, as a rule, to an increase in the service life of transformer against normal. In this case the service life of transformer can become so/such considerable, that the transformer according to some its technical indices (level of insulation, no-load loss, etc.) will become obsolete earlier than its insulation it is worn out. Therefore in operation sometimes they consider it possible to allow/assume the work of transformer with certain excess of nominal load, i.e., with overloading, but, however, so that the service life of transformer would be not less than 20-25 years. The permissible overloadings are subdivided into normal ones and emergency ones.

The normal load factors are allowed/assumed depending on the duty factor of the diurnal graph/curve of load (load factor), and also due to the underloading of transformer in summer.

The permissible overloadings depending on the duty factor of the diurnal graph/curve of load determine, using the diagram of the load-carrying capacity of transformer (Fig. 23-2), along the axis of abscissas of which is deposited/postponed the duration of load peak in hours, and along the axis of ordinates - ratio of peak load to nominal $\left(k=\frac{I_{макс}}{I_{ном}}\right)$. On the diagram it is given of eight curves for

the different values of factor of load $k_н$.

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By factor of the load (see Chapter 4) or, otherwise, the duty factor of the diurnal graph/curve of load is called the ratio of the area, limited by diurnal graph/curve, to the area of the rectangle, sides which are the abscissa, equal to 24 h, and the ordinate, equal to the maximum of graph/curve $I_{макс}$, i.e.

$$k_н = \frac{\Sigma(It)}{24I_{макс}} = \frac{I_{ср}}{I_{макс}}, \qquad (23\text{-}2)$$

where Σ (It) - an area of the graph/curve of the load;

$I_{макс}$ — maximum current of load in the days;

$I_{ср}$ — daily mean current of load.

After determining value $k_н$ and knowing duration in hours n of peak load, according to diagram in Fig. 23-2 it is possible to determine coefficient of k and, therefore, the permissible peak load of transformer $I_{макс} = kI_{ном}$ or $S_{макс} = kS_{ном}$.

Diagram in Fig. 23-2 is constructed for the transformers, which work under nominal temperature conditions. For the transformers,

established/installed in the place where θ_{0cp} is different from 5°C, it is possible to use this diagram, but in this case ordinates k should be multiplied to coefficient of A:

$$A = 1 + \frac{5 - \theta_{0cp}}{100}. \qquad (23\text{-}3)$$

Permissible overloadings by winter due to underloading by summer. Load of transformers by the summer usually lower than load in winter months and lower than nominal; therefore the wear of insulation in the summer period of less than the normal. This allows in winter months without damage for the service life of transformer to increase its overloading in comparison with that that is obtained according to diagram in Fig. 23-2.

For determining the permissible overloading of transformer by winter due to its incomplete loading summer established/installed the following simple rule: if the maximum of the average/mean diurnal graph/curve of load in summer months (June, July, August) is less than the nominal power of transformer, then in winter months (November, December, January, February) is allowed/assumed the overloading of transformer in size/dimension of 1o/o for each of a percent-percentage by summer, but it is not more than 15o/o.

Both rules of the normal load factor, i.e., according to diagram in Fig. 23-2 and present, are related to all transformers with

natural oil and forced ventilation. These rules can be applied together, only the overall amount of g-force according to both rules is limited to 30o/o.

With the use of both rules in cases when the temperature conditions of the cooling medium differ from of nominal, the establishment permissible overloadings should be produced taking into account the translation of the nominal power of transformer according to formula (23-1).

Example 23-1. Transformer with a nominal power of 1000 kVA is established/installed in the unheated ventilation area in the locality where the maximum and average annual values of the temperatures of air with respect to 35 and 5°C. The duty factor of diurnal graph/curve $k_н = 0.7$; the duration of peak load a the winter day n=6 h; the maximum of the average/mean diurnal graph/curve of load in summer months composes 880 kVA. To determine the permissible peak load of transformer in winter months.

We accept a difference in the temperatures the entering the chamber/camera and emerging from it air coolant of the equal to 15°C. Under this condition the average annual temperature of that cooling the transformer of air will compose $\vartheta_{0\,cp} = 5+8=13°C$. In view of a difference in this average annual temperature from nominal the power

of transformer must be converted. According to formula (23-1)

$$S'_{ном} = 1\,000\left(1 + \frac{5 - 13}{100}\right) = 920 \ ква.^{(1)}$$

Key: (1). kVA.

For $k_н = 0,7$ and n=6 h according to diagram on Fig. 23-2 we find k=1.14, i.e., through diagram tne permissible overloading depending on the duty factor of the diurnal graph/curve of load composes 14o/o.

The underloading of transformer by summer and permissible for it due to this overloading by winter they ccmpose

$$p\% = \frac{920 - 880}{920} 100 = 4,5\%.$$

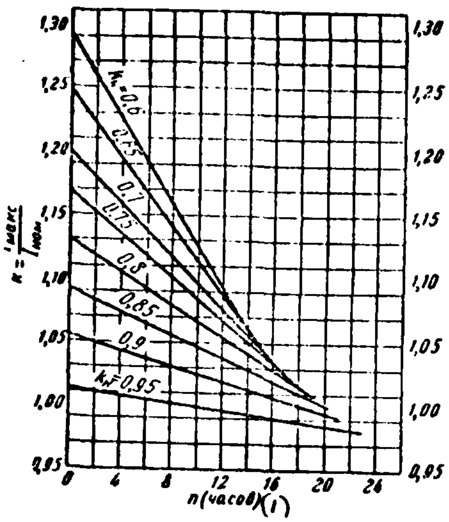

Fig. 23-2. Diagram of the load-carrying capacity of tank transformers.

Key: (1). (hours).

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In all the permissible overloading with respect to both rules composes 14+4.5=18.5o/o.

Consequently, in winter months transformer can be loaded to

$S = 920 \cdot 1{,}185 = 1090$ ква.(1)

Key: (1). kVA.

Emergency overloadings. With the work of transformer even with

the normal load factors the wear of the insulation of its windings nevertheless proves to be less than the normal wear, available with 24-hour permanent nominal load. Consequently, with the normal load factors not only is retained the normal service life of transformer, but in the wear of its insulation remains the sufficient reserve, which can be used for, other not planned/glide in operation overloadings. As the latter there can be, for example, emergency overloadings on leaving from work of one of the working transformers.

According to PUE (section 1, § I-2-37) and to resolution of technical control MES (Nc 15/E from 4/XII 1958) during the emergency modes of work the overloading of transformers is allowed/assumed to 40o/o to the period of the maximum of the general/common/total diurnal duration not more than 6 h during not more than 5 days. In this case the duty factor of the diurnal graph/curve of the load of transformer under conditions of overloading must be not more

$$k_{\text{н}} = \frac{I_{\text{ср}}}{1{,}4\, I_{\text{ном}}} \leqslant 0{,}75. \qquad (23\text{-}4)$$

With this overloading the wear of insulation, naturally, sharply grows/rises. Accordingly [L. 23-1] with 40o/o overloading transformer in 24 hrs "becomes obsolete" whole month, and in 5-6 days - about half a year. However, taking into account that a similar emergency mode can occur not more than 2-3 times for entire service life of transformer, or indicated above facilitating conditions and that

under normal conditions the wear usually is considerably lowered/reduced, is counted the overloading of that permitted indicated.

Emergency overloadings are allowed/assumed without depending on the previous load and the temperature of the cooling medium. In this case in hot season if necessary one should apply the intensive cooling, achieved, for example, by the installation of supplementary fans and supplementary radiators (see §23-3).

23-3. Cooling systems of transformers.

The cooling systems of transformers it is possible to break into the following forms: 1) oil (tank transformers) and 2) air (air-immerseds transformer).

The fundamental methods of cooling the tank transformers they are: 1) the natural oil; 2) the natural oil and artificial (forced) air; 3) oil-water cooling even 4) oil-air cooling.

Oil-immersed natural cooler. The heat, isolated in windings and magnetic circuit of transformer, is transmitted to surrounding oil, and from it through the walls of tank and the cover/cap - to which surrounds transformer air. To the heat removal into the environment

contributes the gravity circulation of oil within transformer, caused by the fact that heated oil rises under cover/cap, and cooled in the walls of tank as heavier is omitted.

In the transformers of small power the tanks have flat surface. In the transformers of large power for the best heat removal into surrounding air are applied the tanks with the increased cooling surface: tubular (Fig. 23-3), and also equipped with special tubular radiators (Fig. 23-4).

Natural oil and forced air cooling. Oil-immersed natural cooler is insufficient for cooling the transformers of large power. For the latter great use/application obtained forced ventilation.

In transformers with forced ventilation tubular radiators are forcedly blown out/blown off by air from several engine- fans 1, placed on two within each radiator in space between its tubes (Fig. 23-4). Electric motors - with short-circuited rotor, the power of every 150 W.

The presence of several fans makes it possible to disconnect part of them with the low temperature of air or the small load of transformer, which reduces the expenditure of electric power for cooling of transformer. If necessary the start and the stop of fans

automate.

Transformers with forced ventilation allow/assume work, also, with completely off blast, if the load of transformer is equal or less than 70o/o nominal, and also with loads 70-100o/o of nominal, but when the temperature of oil does not exceed 55°C.

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Oil-water cooling. To Baku transformer they will connect centrifugal pump 1 (Fig. 23-5), which takes away/gathers more hotly oil from the upper part of the tank and distills it through coolant 2. From coolant oil returns to the lower part of the jacket. Over the tubes of coolant flows/occurs/lasts the cooling water, and in interturbine space under greater than water, pressure moves oil.

Transformers with oil-water cooling must, as a rule, work with the connected cooling without depending on load. Is explained this by the fact that the cooling surface of these transformers, which have flat tanks, is so small that it cannot weigh out even no-load losses of powerful/thick transformers. Oil-water cooling system in comparison with those examined is above more expensive and it is less convenient in operation; therefore it they apply only for very powerful/thick transformers.

In transformers with oil-air cooling provide for the forced circulation oils through air coolers.

In air-immerseds transformer the heat is abstracted/removed by the natural flow of surrounding air. A similar method of cooling proves to be sufficient only for the transformers of small power, what are only and manufactured with dry ones. The advantages of dry ones, transformers are simplicity of construction/design and fire safety as a result of the absence of bolt oil, and also comparatively small overall sizes.

23-4. Expanders and safety devices of transformers.

Expanders. All transformers, with exception of dry ones, pour by oil, obtained as a result of the distillation of oil. In the process of the work of transformer changes heating oil, in consequence of which changes its space. To avoid the discharge of oil outside during its expansion in the transformers of small power oil they do not add to the top of cover/cap. In this case oil level they accept such so that at all permissible modes/conditions of the work of transformer and temperature of surrounding air to 35°C the space of oil would not exceed the tank volume. Tank is on top capped with special plug from

opening through which is passed the air, displaced from tank during heating oils and sucked into tank during its cooling.

In the sucked-in into transformer air are contained oxygen and moisture, in view of which oil is oxidized and is moistened (oil possesses large hygroscopicity). Oxidation and moistening cause the damage of oil and as consequence decrease in its dielectric strength and appearance of acid and slime. With an increase in the contact surface of oil with air this oxidation process and moistening of oil is amplified.

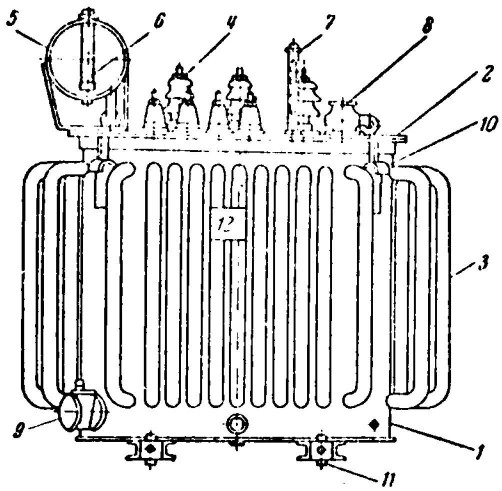

Fig. 23-3. Transformer three-phase with oil-immersed natural cooler, with tubular tank. 1 - tank; 2 - cover/cap; 3 - tube; 4 - wall entrance insulators; 5 - expander; 6 - oil-level gauge; 7 - thermometer mercury; 8 - tap/crane for filling of oil; 9 - bleeder of oil; 10 - clamp for lifting the transformer; 11 - rollers for the movement of the transformer; 12 - certified/rating table.

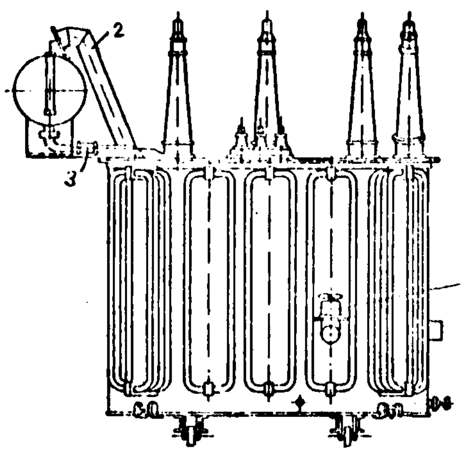

Fig. 23-4. Transformer with forced ventilation with tubular radiators.

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Taking into account this, the transformers of average and large power supply with the expanders (Fig. 23-3 and 23-4), which make it possible to completely pour tank by oil and decreasing the contact surface of oil with air, and consequently, its oxidation and moistening.

The expander (Fig. 23-6), which usually has cylindrical form, installs in the bracket, fastened/strengthened to the cover/cap of transformer. With transformer the expander is connected by the conduit/manifold whose one end/lead is welded-in into the cover/cap of transformer, and other 5 - into the lower part of the expander and so that it would be above the bottom of expander. By the latter is removed, incidence/impingement into the tank of the transformer of the decomposition products of oil and residues/settlings, which are saved in the lower part of the expander. Slime and residues/settlings periodically drive out through the drain mud cock 4. The expanders of the transformers of average/mean power supply with plug 6 with openings/apertures for suction and displacement of air with a change of the space of containing in them oil. The expanders of the transformers of large power for the same target supply with tube with

3 whose end/lead has bored cork and small/fine wire gauze, which prevents from incidence/impingement into the expander of solid suspended particles from surrounding air. The space of expander usually composes 8-10o/o of space of oil in the tank of transformer.

For observation of oil level on the lateral wall of expander is established/installed oil gauge 1, fulfilled in the form of glass tube in metallic mounting/case. On the bottom of expander about oil gauge are plotted/applied by paint/color three control features, which correspond level of oil at temperatures -35, +15 and +35°C.

Protective tube. Short circuit within transformer is usually accompanied by the intense decomposition of oil and by the formation/education of a large quantity of gases. In this case the pressure within transformer sharply is raised, which can lead to the decomposition of tank. To avoid this all powerful/thick transformers have protective tube 2, established/installed on cover/cap (Fig. 23-4); free end the tubes close with glass disk. With the pressure increase within transformer oil rises along tube, glass disk strands itself and oil is rejected outside.

Gas relay 3 (Fig. 23-4) serves for the cutoff/disconnection of transformer during the internal damages, which are accompanied by liberation of gas. Relay consists of the cast cast iron container, of

which they are placed one above another two floats. By relays it is established/installed on the path of motion of oil in the conduit/manifold, which connects transformer with expander.

By gas relays are equipped transformers in power 1000 kVA and it is above.

Let us additionally note that recently the power transformers of large power began to supply with built-in current transformers which are installed within the tank of transformer in its wall entrance insulators from the side of the increased voltage [l. 19-1].

23-5. Regulating the voltage of transformers.

The load of the users of electric power is never constant, but it changes both in the course of twenty-four hours and during season. A change in the load of users produces change in the load of their feeding electric system. The latter is accompanied by a change in the loss of line voltage and as consequence by a change in the voltage on the busbars of the reducing substations and on the terminals/grippers of electrical receivers.

In practice they resort to different methods of regulating the line voltage which are examined in special textbooks [l. 7-1] along

electrical networks and transmission lines. In particular, greatly is used extensively regulating voltage by a change in the transformation ratio of transformers. On some installations the voltage is regulated with the aid of injector transformers.

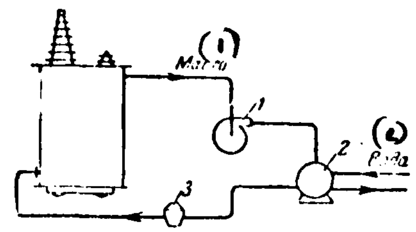

Fig. 23-5. Schematic of oil-water cooling of transformer. 1- oil pump, 2 - oil cooler; 3 - air separator.

Key: (1). Oil. (2). Water.

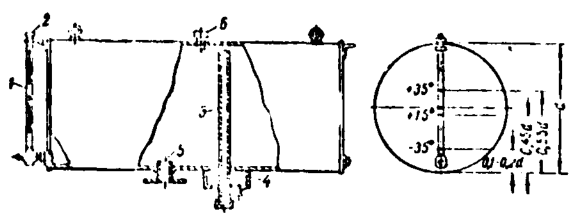

Fig. 23-6. Expander of transformer.

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There are two types of the transformers: the transformers in which it is possible to change transformation ratio only after their cutoff/disconnection from network/grid, and the transformers the

transformation ratio of which can be changed during their work, i.e., under load.

First type transformers are installed in those all cases when in the process of operating transformers not at all they utilize for regulating the voltage on prolonged seasonal operating cycle.

The second install when the technical-economic calculations during the design of network/grid show that by most economical is regulating line voltage by changing the transformation ratio of its feeding transformers.

Transformers with ratio regulation under load are used extensively in power systems, their placing on district and local substations, and also on power plants.

Regulating voltage by a change in the transformation ratio of transformers without load. The transformation ratio of transformers is changed with the aid of the supplementary branchings, provided for on their windings. Double wound transformers usually have supplementary branchings on high-voltage windings, and triple-wound - on the windings of the highest and average of voltages. The windings of the transformers of small and average/mean power normally have two supplementary branchings for obtaining the transformation ratio,

different from nominal to +5 and -5o/o. The windings of all transformers of large power have four supplementary branchings for obtaining the transformation ratio, different from nominal to +5; +2.5; -2.5 and 5o/o. In certain cases of the winding of transformers have other versions of branchings.

For a double wound transformer (Fig. 23-7) approximately it is possible to write whence

$$\frac{U_{BH}}{U_{HH}} = \frac{w_{BH}}{w_{HH}},$$

which
or

$$U_{HH} = \frac{U_{BH} w_{HH}}{w_{BH}},$$

$$U_{BH} = \frac{U_{HH} w_{BH}}{w_{HH}}, \qquad (23\text{-}5)$$

where U_{BH} — load voltage of the winding VN;

U_{HH} — load voltage of the winding NN;

w_{BH} — number of connected turns of the winding VN;

w_{HH} — number of turns of the winding NN.

If in step-down voltage transformer, conducted/supplied to primary winding, increased, then for maintaining load voltage of secondary winding to previous ones it is necessary a number of

connected to network/grid turns of primary winding to increase; an increase in load voltage of secondary winding with the decrease of the voltage, conducted/supplied to primary winding, is achieved by the decrease of a number of connected turns w_{BH}.

Switching from one branching to another is realized with the aid of the special switch whose handle is brought out to the cover/cap of transformer.

For switching from one branching to another the transformer must be disconnected both from the network/grid of primary and from the network/grid secondary voltage.

Example of 23-2. Step-down tapped transformer for ratio regulation to ±5o/o (Fig. 23-7) is connected to power line by the terminals/grippers of the fundamental conclusion/output AX_2; load voltage of primary winding AX_2 increased by 5o/o. What it is necessary to make in order to preserve load voltage of secondary winding the same as before? Response/answer. For this, first of all, necessary to disconnect transformer, i.e., to disconnect its switch and disconnectors, and then to disconnect wire from terminals/grippers X_2 and to connect it to terminal/gripper X_1. After this transformer can be included/connected.

If load voltage of primary winding decreases by 5o/o, then wire from terminal/gripper X_2 it is necessary to reconnect to terminal/gripper X_3.

In the step-up transformer secondary winding is the high-voltage winding (with branchings). Therefore for maintaining constant load voltage of secondary winding with the decrease of load voltage of primary winding it is necessary a number of turns $w_{вн}$ to increase, and with an increase in load voltage of primary winding, on the contrary, to decrease.

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Regulation off-shoots depending on voltage and power of transformers make either near the neutral particle of windings (Fig. 23-7), or in their middle part. In the latter case the winding is divided into two parts (Fig. 23-8).

Regulating voltage by a change in the transformation ratio of transformers under load. With a change in the transformation ratio of transformer under load the passage from one off-shoot of winding to another is produced without the interruption of current in the fed network/grid, which is achieved by simultaneous connection to the period of the transfer/translation/conversion of two regulation off-shoots. The passage indicated is produced with the aid of special switching system, structurally/constructionally being part transformer itself. The transformers, supplied with this switching system, call transformers with the built-in regulating. There are many different schematics of the devices/equipment of the built-in regulating. Let us become acquainted with one of them, that is adapted for Soviet transformers (Fig. 23-8).

Device/equipment consists of slide contacts a and b, contactors K-1 and K-2 and reactor R, from the middle of turns of which is made the off-shoot, connected with one of the halves of the winding of transformer. Under normal conditions for work both slide contacts a and b are found on fixed contact of one of the off-shoots both contactors K-1 and K-2 are included. The current of load flows/occurs/lasts through both slide contacts, both contactors and both halves of the winding of reactor. Since currents and, consequently, also magnetic fluxes in both halves of the winding of reactor are nearly equal and opposite, then under normal conditions for work the resulting magnetic flux of reactor (leakage flux) is small, its inductive reactance is negligible and the loss of voltage in reactor is insignificant (5-6o/o of single-stage voltage of regulating). Upon transfer from one off-shoot to another, for example from 2 by 3, disconnect contactor K-2 and slide contact b they move to fixed contact off-shoots 3. After this contactor K-2 they switch on, as a result of which the armature coil, the prisoner between off-shoots 2-3, are locked to reactor. In this case through each half reactor flows/occurs/lasts the half of the current of load and the cross current, caused by voltage between off-shoots 2 and 3.

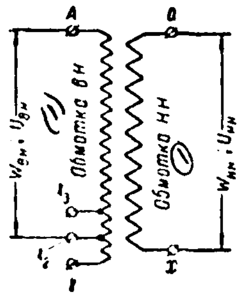
Cross current in both halves reactor has identical direction,

and the current of load - different. Therefore of the strength of resulting current in each of the halves reactor they are different: in one it is equal to vector sum of the half of the current of load and cross current, but in another - their geometric difference. Because of this the magnetic fluxes of both halves reactor completely are not compensated, the resulting magnetic flux and, consequently, also inductive reactance of reactor they grow/rise. The latter limits the value of cross current to the specific permissible value.

After the start of contactor K-2 is disconnected the contactor K-1, slide contact a move to fixed contact off-shoots 3 and then is connected contactor K-1. On this the process of switching to another off-shoot concludes.

In transformers with the built-in regulating adjusting device can be built in primary or secondary winding. For the purpose of the maintenance of exciting current of transformer by constant and close to nominal switching system to rationally build in into that winding from the side of which in the process of operation changes the applied voltage. For example, in the step-down transformer, which feeds from the network/grid whose voltage frequently changes, switching system it is expedient to have in high-voltage winding.

A range and a number of steps/stages of ratio regulation depending on power and conditions for the work of transformer can be different.



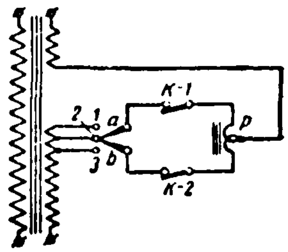


Fig. 23-8.

Fig. 23-7. Winding diagram of one phase of three-phase transformer with regulation off-shcots.

Key: (1). Winding.

Fig. 23-8. Diagram switching systems for changing transformation ratio of transformer under load.

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So, in powerful/thick transrormers a number of steps/stages of adjustment reaches to 8-10, and the range of regulating - to ±12o/o.

Reactor and device/equipment with mobile and fixed contacts arrange/locate in the tank of transformer, and contactors are mounted on insulating plate/slab, they place into the steel box, flooded by transformer oil, and they strengthen/fasten from the face of the tank

of transformer. To arrange/locate contactors inside the jacket of transformer is impossible, since the arc on the contacts of contactor, which is formed in control, makes the quality worse of oil.

Switching systems supply with the drive mechanisms which are given in action by the electric motors of direct or alternating current. Drive mechanisms are governed/controlled remote with control board, but they can be governed/controlled and it is automatic under the action of voltage relay. Furthermore, always allow for managements by hand.

Soviet plants manufacture the transformers, regulating under load in which is produced on the side of high voltage within limits of ±10o/o of nominal (by eight steps/stages on 2.5o/o). In triple-wound transformers, besides regulating under load on the side of high voltage, is provided for the regulating without load on the side of medium voltage within limits of ±5o/o (four steps/stages on 2.5o/o). In transformers with high voltage to 35 kV inclusively regulation off-shoots are made in the middle part of the windings (it is similar to Fig. 23-8), while in transformers with high voltage 110 kV - near the neutral particle (it is similar to Fig. 23-7). In the latter case the star is formed by the connection of midpoints of the reactors of three phases of adjusting devices.

The apparatuses of adjusting devices of Soviet transformers 110 kV have isolation, designed for voltage 35 kV. In connection with this the neutral particles of transformers 110 kV, whose adjusting devices are arranged/located from the side of neutral particle, must tightly be grounded or be included through dischargers 35 kV.

Regulating voltage with the aid of injector transformer. In this case regulating load voltage is achieved with the aid of special regulating transformer, called booster.

Injector transformer consists of two parts, executed of one or two jackets (Fig. 23-9): sequential transformer and its feeding transformer or autotransformer. Secondary winding of sequential transformer is connected with that winding of main transformer in circuit of which is assumed regulating voltage, and its primary winding they connect up secondary winding of the feeding transformer. The primary winding of the latter they usually connect to the low-voltage winding of main transformer.

In secondary winding of sequential transformer is inducted emf, which geometrically is added to the voltage of the winding of main transformer and it changes thereby its value.

The primary winding of sequential transformer they connect up the feeding transformer on the special diagram according to which one end the windings of sequential transformer connect to the average/mean (neutral) off-shoot H of the feeding transformer, and its another end they connect up midpoint of reactor P of switching system. The latter executed works just as given in Fig. 23-8. With the displacement/movement of contacts a and b of switching system to one or other side from the neutral off-shoot H, i.e., over fixed contacts 5-6-7-8 or 4-3-2-1, inducted in secondary winding of sequential transformer emf proves to be directed to opposite sides: in one case toward an increase in the voltage in the adjustable circuit, and in other - toward the decrease of voltage.

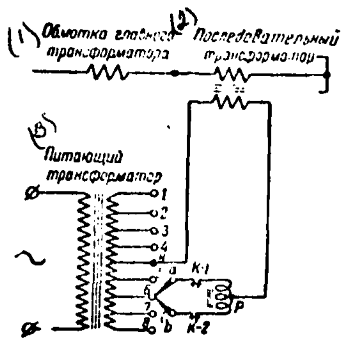

Fig. 23-9. Control circuits of voltage with the aid of injector transformer (it is shown for one phase).

Key: (1). Winding of main transformer. (2). Sequential transformer. (3). Feeding transformer.

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Let us note that secondary winding of sequential transformer usually join up the windings of main transformer from the side of zero so that during the short circuit in sequential transformer its windings would be protected by winding impedance of main transformer.

Injector transformers can be used both for regulating the voltage in value - the so-called longitudinal regulating and for its regulating on phase, transverse regulating. The basic difference

between them consists in the diagram of connection of the windings of the feeding transformer. Fig. 23-10 depicts diagrams and vector diagram of the voltages of the step-up transformer with longitudinal regulating. As can be seen from diagram, with longitudinal regulating the voltages of secondary windings of sequential transformer coincide in phase with the voltages of the high-voltage windings of main transformer.

With the transverse regulating of the winding of the feeding transformer and the ends of its adjusting device connect so that the vectors of the voltages of secondary windings of sequential transformer would be perpendicular to the voltages of the phases of network/grid. Then, changing a quantity and a direction of the off-shoots of adjusting device of the feeding transformer, is the possible to change value and direction of the regulated vector of voltage with respect to basic, i.e., to conduct regulating on phase.

Regulating voltage with the aid of injector transformer finds a use in the transformers of the large power of electrical stations and district substations of power systems. In comparison with the built-in regulating the device/equipment of regulating with the aid of injector transformer is more complicated and considerably more expensive.

23-6. Autotransformers.

Autotransformer in its device/equipment differs from usual transformer in terms of the fact that its primary and secondary windings are not separated, but, on the contrary, connected electrically (Fig. 23-11a).

In the reducing autotransformer (Fig. 23-11a) primary current I_1, being sent from electric power source toward receivers II, flows/occurs/lasts over the part of winding Aa, which contains $w_1=w-w_2$ turns where w - a number of turns of the entire winding Ax. In this case in the part of winding ax is inducted current I'_2, by the directly opposite to current I_1. In the circuit of receivers or, otherwise, in second circuit flows/occurs/lasts current $I_2=I_1+I'_2$ (the angular displacement of currents we do not consider).

Transformation ratio of the autotransformer

$$k_{ат} = \frac{w}{w_2} \approx \frac{U_1}{U_2}. \qquad (23\text{-}6)$$

The power, equal to $S_1=I_1U_1$ (S_1 - power of one phase; U_1 - phase voltage), is called the transfer power of the autotransformer (see explanations to Fig. 23-12).

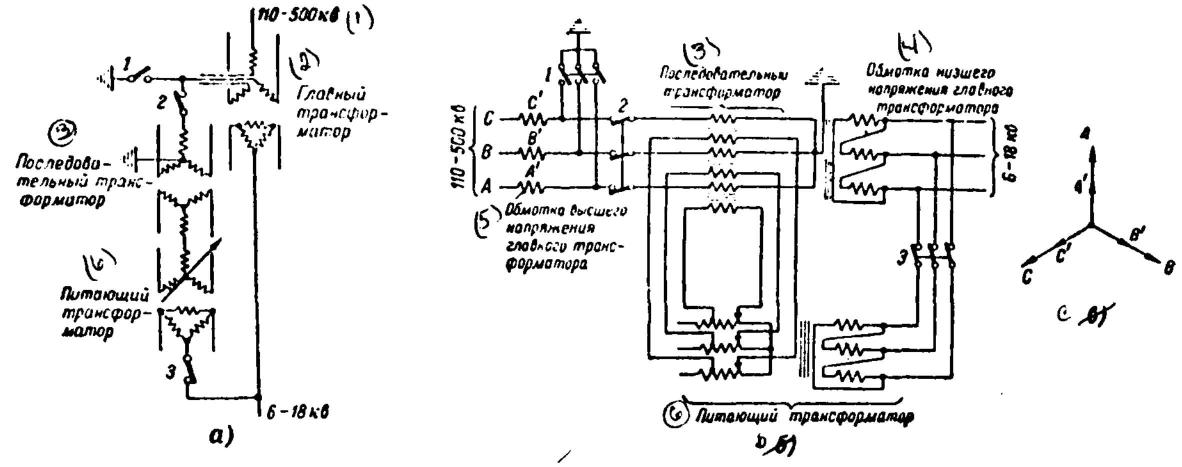

Fig. 23-10. Circuit diagram of injector transformer for the longitudinal regulating of voltage. a) diagram unilinear; b) diagram trilinear; c) vector diagram of voltages.

Key: (1). kV. (2). Main transformer. (3). Sequential transformer. (4). Low-voltage winding of main transformer. (5). High-voltage winding of main transformer. (6). Feeding transformer.

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During the comparison of autotransformer with usual transformer the amount of the transfer power of the first shows, to what power it would be necessary to prepare usual transformer so that it could valuably replace this autotransformer.

The second power of one phase is equal to $S_2=U_2I_2=U_2I_1+U_2I'_2$ (U_2 - phase voltage), i.e., the second power of autotransformer is comprised of two parts: power U_2I_1, called the electrical power which is transferred by primary current directly into second circuit, since both circuits are connected electrically, and power $U_2I'_2$, called the electromagnetic power which is obtained by transformation with the participation of magnetic flux.

Volume and weight of any transformer are determined by the mainly transformed power. Consequently, volume and weight of autotransformer are determined by the mainly electromagnetic power which in autotransformers is called calculaticn or standard. The amount of standard power depends on the relationship/ratio of primary and second voltages and usually comprises only the part of the transfer power of autotransformer. Thus, for instance, with the relationship/ratio of voltages 220/110 kV standard power composes 50o/o, with the relationship/ratio of voltages 400/220 kV - 45o/o, and with the relationship/ratio of voltages 400/110 kV - 73o/o of transfer power.

Since standard power composes only the part of the passage, then, therefore, the standard power of autotransformer composes only

the part of the power of usual transformer. In connection with this the volume, weight and cost/value of autotransformer in comparison with volume, weight and cost/value of the usual transformer of the same power are obtained smaller; transport, installation and installation are facilitated; the losses of electric power in copper of windings and steel of core are also obtained smaller, but efficiency - are above.

Inductive reactance of autotransformers in comparison with usual transformers (at identical power and with voltages) is less, thanks to which it is less than the loss of voltage in autotransformer. The latter improves the conditions of regulating the line voltage, and it also decreases the losses of reactive power.

The advantages of autotransformers can be judged from the comparative data given in Table 23-1. Data are related to single-phase transformers with the identical method of cooling, made from uniform active materials also for the identical levels of testing voltages.

Together with the merits indicated the autotransformers possess the number of the deficiencies/lacks, basic of which are the following.

If we the neutral particle of the windings of autotransformer do not ground, then during single-phase closing/shorting to the earth in the network/grid of high voltage the potential of two other phases of the network/grid of low voltage relative to the earth/ground can increase to the inadmissible, dangerous for its isolation value. To avoid this of the neutral particle of the windings of autotransformers it is necessary to ground tightly or through small inductive reactances.

Consequently, autotransformers can be adapted only in the networks/grids, which work with dully grounded neutrals.

The conditions for the work of high-voltage apparatuses in networks/grids with autotransformers heavier than with usual transformers, in view of the fact that inductive reactance of autotransformers is less, but short-circuit currents are more. In this case especially increase the currents of single-phase closings/shortings to the earth because of the need for the grounding of the neutral particles of all autotransformers. In certain cases the currents of single-phase closings/shortings to the earth can even exceed the currents of three-phase short circuits.

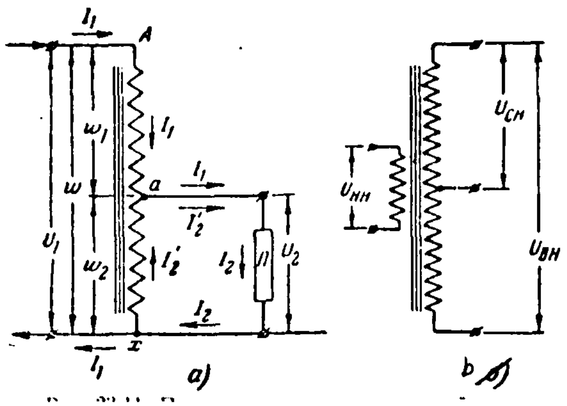

Fig. 23-11. Schematic diagrams of one phase of autotransformers.

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To avoid the latter in the networks/grids of neutral particle in the part of the transformers with separate windings they unground (see Chapter 5), and in the neutral particle of some autotransformers they switch on inductive reactances, than and limit the currents of single-phase closings/shortings to the earth to the strength of currents of three-phase closings/shortings.

In autotransformers the circuit of low voltage is electrically circuital of high voltage, thanks to which with overvoltages in the network/grid of high voltage is possible the passage of the wave of overvoltage into the network/grid of low voltage and as consequence

is possible damage to the isolation and of the apparatuses, established/installed in the network/grid of low voltage. To avoid the damages indicated it is necessary to use reliable surge protection, made in the form of nonlinear resistance arresters, dully joined from both sides of autotransformer winding.

In power systems the autotransformers, made according to diagram in Fig. 23-11a, they do not usually use. There use autotransformers (Fig. 23-11b), which, besides two windings VN and SN, connected electrically, have even separate - third - winding, connected into triangle. The latter has magnetic coupling with the windings VN and SN and serves for compensating the currents of the third harmonic. Besides the compensation indicated, third winding of autotransformers on the reducing substations is used for the nourishment of the adjacent users and connection of the synchronous condensers, and on power stations - for switching of generators. In the latter case the autotransformers are used as those increasing.

Autotransformers with the third winding, utilized for the nourishment of users or connection of generators, fairly often conditionally call triple-wound autotransformers.

For the purpose the most complete uses of advantages of autotransformers the power of the third winding assume/take possibly

less, on the basis of the guarantee of electrodynamic stability of winding with the flow of short-circuit currents. The highest efficiency of the third winding must not exceed the standard power of autotransformer, since otherwise the third winding will be being determining the construction/design of autotransformer. Soviet plants manufacture autotransformers with a third winding whose power composes 25-50o/o of power of inducing windings, i.e., with the relationship/ratio of the power of the windings VN-SN-NN, equal to 100o/o/100o/o/25o/o with 100o/o/100o/o/50o/o (see Table 23-1 and P-5). The voltage of the third winding is selected in accordance with its use and they take as the equal to 6.6; 11; 13.8; 15.75; 18 or 38.5 kV. Inducing windings manufacture to voltages 420 and 242; 420 and 121; 242 and 121 kV, etc. At present autotransformers can be carried out to power to 750 MVA in group (to 250 MVA in phase) and even greater.

Because of the row of advantages in comparison with transformers with separate windings the autotransformers at present begin to obtain the widest application both in our USSR and abroad.

Table 23-1. Data of single-phases transformer 220 kV of Moscow transformer plant.

(1) № по порядку	(2) Связь между обмотками высшего и среднего напряжений	(3) Напряжение холостого хода, кв	(4) Мощность обмоток, Мва	(5) Напряжение короткого замыкания, отнесенное к мощности обмотки ВН, %		
				ВН — СН	ВН — НН	СН — НН
1	(6) Трансформаторная	$\frac{242 \pm 2\times2{,}5\%}{\sqrt{3}} / \frac{121}{\sqrt{3}} / 13{,}8$	82,5/82,5/82,5	22,5	14,0	8,5
2	(7) Автотрансформаторная	$\frac{220 \pm 2\times2{,}5\%}{\sqrt{3}} / \frac{121}{\sqrt{3}} / 10{,}5$	80/80/40	10,5	36,0	23,0

(1) № по порядку	(8) Вес активной стали, т	(9) Вес меди, т	(10) Вес выемной части, т	(11) Общий вес без масла, т	(12) Вес масла, т	(13) Внешние размеры (длина, ширина, высота), мм	(14) Потери в стали, %	(15) Потери в меди, %	(16) Суммарные потери, %
1	61,5	14,9	96,4	138	61,8	6 800×3 800×8 250	0,24	0,48	0,72
2	25,5	12,8	49,0	86	45,1	5 850×2 950×7 620	0,14	0,31	0,45

Key: (1). No in order. (2). Connection/communication between windings of highest and average of voltages. (3). Open-circuit voltage, kV. (4). Power of windings, MVA. (5). Impedance voltage, in reference to power of winding VN, o/o. (6). Transformer. (7). Autotransformer. (8). Weight of active steel, t. (9). Weight of copper, t. (10). Weight of cutting part, t. (11). Total weight without oil, t. (12). Weight of oil, t. (13). Overall sizes (length, width, height), mm. (14). Losses in steel, o/o. (15). Losses in copper, o/o. (16). Summary losses, o/o.

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In conclusion let us examine the modes of operation of triple-wound autotransformers during their use as those reducing and increasing. The examination of modes/conditions let us conduct on concrete/specific/actual triple-wound autotransformer in three-phase nominal transfer power 500 MVA with the relationship/ratio of the power of the windings (VN-SN-NN) by 100o/o/100o/o/50o/o. Voltages of the windings VN and SN are equal to with respect 420 and 242 kV. For simplicity let us accept transformation ratio equal to 400/200 kV. Under these conditions of nominal power $S_{ном} = 500$ MVA in 400 kV corresponds the current 720A, and with 200 kV current 1440A.

Fig. 23-12 shows current distribution in the windings of one phase during six different modes of operation of autotransformer. Modes/conditions a and b correspond to the work of autotransformer as that reducing, while modes/conditions c and d - as that increasing.

In mode/conditions a the winding NN at idling, i.e., it plays the role only of pole face winding. Power $S_{ном}$ is transferred from the side VN to side SN in two ways: one half - electrically, and another - electromagnetic.

In mode/conditions b one half power $S_{ном}$ is transferred to side SN electrically, and another - into the winding NN electromagnetically. With a similar relationship/ratio of power on

sides SN and NN the current of load in the part of winding ax does not flow/occur/last.

In mode/conditions c the nominal power of winding NN, equal to the half of the nominal transfer power of autotransformer, is transferred to the winding VN. The latter in this case proves to be loaded only half that considerably are decreased the energy losses in windings. A decrease in the losses in this mode/conditions represents one of the advantages of the use/application of triple-wound autotransformers as those increasing on power stations.

In mode/conditions d the nominal power of the winding NN is transferred into the winding SN electromagnetically. Inducing winding in the limits of entire its length, i.e., both in the part of Aa and in part of ax, is carried out one section, in our case of the calculation of passage 720a. Consequently, in this mode/conditions the part of inducing winding ax, belonging to the winding SN, proves to be loaded completely. It is clear that additional power, for example from the side VN, in this mode/conditions to issue into the winding SN is not represented by possible.

In mode/conditions e the winding VN is loaded to the full/total/complete nominal transfer power the half which to it is transferred electromagnetically from the side NN and, etc. - from the

side SN electrically. Consequently, in this mode/conditions autotransformer permits half its nominal transfer power to pass from the side SN with the completely loaded winding NN. The latter usually is used at the electrical stations where the use/application of the increasing triple-wound autotransformers in a number of cases makes it possible to simplify the diagram of the electrical connections of station, to decrease a quantity of installed transformers, switches and other apparatuses of high voltage and to obtain thereby significant savings in capital expenditures.

Mode/conditions f with the relationship/ratio of power indicated is inadmissible, since in this case part ax of inducing winding is overloaded one and a half times. This mode/conditions is possible only with a corresponding decrease in the power flux from the winding NN.

From the point of view of the use of autotransformers and decrease of the losses of electric power the best modes/conditions are modes/conditions a and b, i.e., with the work of autotransformers as those reducing. However, also during the use of autotransformers as those increasing in very many cases they prove to be more advantageous than usual transformers with separate windings.

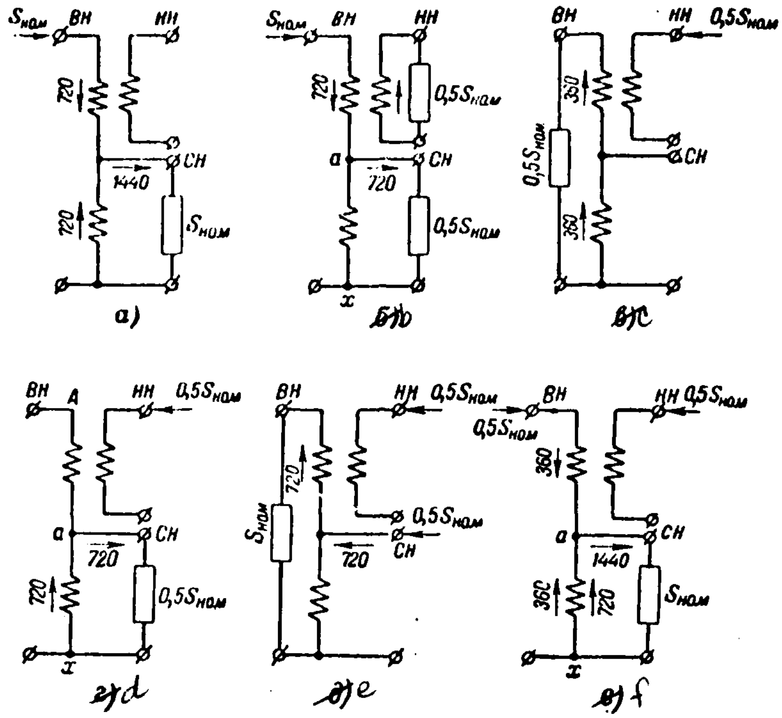

Fig. 23-12. Current distribution in the windings of triple-wound autotransformer during different operating modes.

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Appendices.

P-1. Fundamental characteristics of turbogenerators.

(1) Тип генератора	(2) Номинальная мощность		cos φ	(3) Номинальное напряжение, кв	(4) Сверхпереходное индуктивное сопротивление x''_d	(5) Возбудитель		(6) Вес, т	
	(7) Мва	(8) Мвт				(9) мощность, квт	(10) напряжение, в	(11) ротора	(12) общий
				(13) *Турбогенераторы с воздушным охлаждением*					
Т2-0,75-2	0,938	0,75	0,8	0,4/0,23 6,3	0,12 0,141	20	60	1,65	8,2
Т2Б-1,5-2	1,875	1,5	0,8	0,4/0,23 3,15; 6,3	0,154 0,115	20	60	2,25	10,8
Т2-2,5-2	3,125	2,5	0,8	3,15; 6,3	0,091	40	115	3,8	18,3
Т2-4-2	5,0	4,0	0,8	3,15; 6,3	0,111	50	150	4,1	20
Т2-6-2	7,5	6,0	0,8	3,15; 6,3	0,12	50	150	6,2	25
Т2-12-2	15	12	0,8	6,3 10,5	0,115 0,131	75	230	9,5	40,3
				(14) *Турбогенераторы с водородным охлаждением*					
ТВС-30	37,5	30	0,8	6,3 (15) 10,5	0,143 0,152	150	230	16,5	88
ТВ-60-2	75	60	0,8	6,3 и 10,5	0,132	170	230	31	154
ТВ2-100-2	117,5	100	0,85	13,8	0,138	300	400	42	236
ТВ2-150-2	166,5	150	0,9	18	0,122	360	450	58,6	340
ТВФ-100-2	117,5	100	0,85	10,5	0,183	460	300	29,3	—
ТВВ-165-2	194	165	0,85	18	0,235	—	—	34	—
ТГВ-200	235	200	0,85	15,75	0,19	1 150	535	48	289
ТВФ-200	235	200	0,85	11	0,18	1 150	360	51	—
ТГВ-300	353	300	0,85	20	0,198	1 400	465	54,5	—
ТВВ-300	353	300	0,85	20	0,18	1 500	515	55	365

Notes:

1. All turbogenerators are double-pole with speed rotations/revolutions 3000 r/min.

2. Turbogenerators of types TVS, TV and TV2 have surface cooling

by hydrogen of windings of stator-rotor unit.

Turbogenerators of the type TGV-200 (KhETZ) are carried out with direct internal cooling by hydrogen at a pressure 3 Am(gage) of the windings of stator-rotor unit.

Turbogenerators of the type TVF (plant "electric power") are carried out with surface cooling by hydrogen at the pressure by 2 or 3 Am(gage) of the stator winding and by internal cooling of the coils of rotor (forced cooling - F).

3. Characteristics of turbogenerators of types TGV-300 (KhETZ) and TVV-300 (plant "electric power") - preliminary according to specifications projects. A turbogenerator of the type TGV-300 is designed with internal cooling by hydrogen at a pressure 3 Am(gage) of the winding of stator-rotor unit.

A turbogenerator of the type TVV-300 is designed with the internal cooling of the coils of stator by the distilled water and the rotor winding by hydrogen at a pressure 3 Am(gage).

Key: (1). Type of generator. (2). Nominal power. (3). Nominal voltage, kV. (4). Ultratransitory inductive reactance. (5). Agent. (6). Weight, t. (7). MVA. (8). MW. (9). power, kW. (10). voltage, in.

(11). rotor. (12). general/common/total. (13). Turbogenerators with ventilation. (14). Turbogenerators with hydrogen cooling. (15). and.

P-2. Fundamental characteristics of powerful/thick vertical hydraulic generators.

(1) Тип генератора	(2) Скорость вращения, *об/мин*	(3) Номинальная мощность, *Мва*	(4) Номинальное напряжение, *кв*	(5) Сверхпереходное индуктивное сопротивление x''_{*d}	(6) Вес, *т*	
					(7) ротора	(8) общий
СВ425/135-16	375	33	10,5	0,29	99	215
СВ465/210-16	375	66	10,5	0,21	160	360
ВГС 325/64-24	250	5,0	10,5	0,36	28	65
ВГС 375/69-24	250	8,75	6,3	0,34	50	100
СВ 425/60-24	250	10	6,6	0,27	49	99
ВГС 445/60-28	214	9,4	10,5	0,22	52	108
ВГС 375/59-28	214	9,4	6,3	0,20	64	120
ВГС 525/99-28	214	18,75	10,5	0,27	89	195
СВ 546/90-32	187,5	18,7	10,5	0,36	108	205
ВГС 525/119-32	187,5	20	10,5	0,22	102	214
СВ 566/125-32	187,5	30	10,5	0,20	135	290
СВ 655/110-32	187,5	44	10,5	0,30	160	327
СВ 546/80-36	167	15	6,6	0,38	85	193
ВГС 527/84-40	150	12,5	10,5	0,24	85	200
СВ 546/90-40	150	15,6	6,3	0,3	91	191
ВГС 525/114-40	150	17,5	10,5	0,37	98	211
СВ 566/125-40	150	23,5	10,5	0,23	141	246
СВ 750/75-40	150	27	10,5	0,20	170	316
СВ 655/155-40	150	44	10,5	0,21	220	450
СВ 850/190-40	150	100	10,5	0,19	452	845
ВГС 700/[illegible]-48	125	26,3	10,5	0,21	138	265
СВ 850/190-48	125	85,5	13,8	0,23	325	660
СВ 1190/250-48	125	235	15,75	0,21	685	1 400
СВ 840/150-52	115,4	50	10,5	0,20	235	520
ВГС 700/80-56	107	16,25	10,5	0,22	127	265
ВГС 700/100-56	107	22,5	11	0,23	148	295
СВ 500/76-60	100	18	10,5	0,27	168	350
СВ 800/105-60	100	30	10,5	0,30	223	430
СВ 850/120-60	100	40	10,5	0,23	216	468
СВ 1240/245-64	93,6	180	15,75	0,19	770	1 500
СВ 1030/120-68	88,2	52	10,5	0,20	274	520
СВ 1160/180-72	83,3	103,5	13,8	0,26	491	986
СВ 895/170-80	75	30	10,5	0,23	300	535
СВ 1100/145-88	68,2	50	15,75	0,23	402	834
СВ 1500/200-88	68,2	123,5	13,8	0,14	765	1 410
СВ 1135/80-96	62,5	28,75	10,5	0,23	230	460
СВ 1340/150-96	62,5	71,5	13,8	0,21	513	1 076
СВ 1500/170-96	62,5	117,65	13,8	0,21	592	1 170
СВ 1250/115-108	55,5	33,4	10,5	0,16	280	555

Note. A designation of the type of the hydraulic generator: SV - series of the powerful/thick vertical hydraulic generators; VGS - series of the vertical hydraulic generators of individual

performance. Numerator of fraction denotes outside diameter, and denominator - length of active steel of stator in centimeters. Numeral after line indicates a number of poles of rotor (2p).

Key: (1). Type of generator. (2). Speed of rotation, r/min. (3). Nominal power, MVA. (4). Nominal voltage, kV. (5). Ultratransitory inductive reactance. (6). Weight, t. (7). rotor. (8). general/common/total.

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P-4. Fundamental characteristics of the power transformers of Soviet plants.

The type of transformer they conditionally designate by letters and numerals. By letters they designate a number of phases, cooling system, number of windings and lightning resistance of transformer, but by numerals - nominal power of transformer and its high voltage.

The letterings: OD, OTs, TM, TS, TD, TTs, TDTs, TDN, ODT, TDT, TDTG, etc. The first letter indicates a number of phases (O - single-phase, T - three-phase); the second, and in some types of transformers the second and third letters indicate the cooling system (M - natural oil, S - air-immersed transformer, i.e., with natural

air cooler, D - with forced ventilation (with blowing), Ts - with the forced circulation of oil and water cooling, DTs - with the forced circulation of oil through air coolers). The following letters they indicate a number of windings (T - three), a method of ratio regulation (N - under load), and also to the lightning resistance of transformer (G - lightning-proof). Numerals superscribe the fraction, whose numerator indicates the nominal power of transformer in kilo-volt-amperes, and denominator - high kilcvoltage.

Examples of the designations of the types:

TM-180/6 - three-phase with oil-immersed natural cooler, nominal power 180 kVA, high voltage 6 kV ODTG-60000/220 - single-phase with forced ventilation, triple-wound, lightningproof, nominal power 60000 kVA, high voltage 220 kV.

Let us note that the autotransformers in contrast to transformers at the end of lettering have a letter A, for example: ODTGA-80000/220.

Three-phase transformers with built-in ratio regulation under load are manufactured:

with high voltage 10 kV - by power 750, 1000, 1800 and 3200 kVA;

with high voltage 35 kV - by power 1800; 3200; 5600; 7500; 10000, 15000, 20000, 31500 kVA;

with high voltage 110 kV - by power 3200; 5600; 7500; 10000, 15000, 20000, 31500, 40500 and 60000 kVA;

with high voltage 220 kV - power 10000, 15000, 20000, 31500, 40500 and 60000 kVA.

Regulating is produced on the side of high voltage.

In triple-wound transformers, besides regulating under load on the side of high voltage, is provided for also adjustment of transformation ratio without load on the side of medium voltage. The latter is produced by off from network/grid transformer.

The given below tables of technical characteristics of two- and triple-wound transformers are comprised on the basis of the catalogues to power transformers and the information materials of Moscow and Zaporozh'ye transformer plants, and also based on materials of Electroheat-plan and Leningrad division of Gidroenergoproyekt.

P-3. Fundamental characteristics of the synchronous condensers.

(1) Тип синхронного компенсатора	(2) Номинальная мощность, Мва	(3) Номинальное напряжение, кв	(4) Сверхпереходное индуктивное сопротивление x''_{*d}	(5) Возбудитель		(8) Общий вес, т
				(6) мощность, квт	(7) напряжение, в	
КС 5000-6	5	6,3	0,16	34	65	18,8
КС 7500-6	7,5	6,6	0,15	50	115	24,6
КС 15000-6	15	6,6	0,15			53,1
КС 15000-11	15	10,5	0,18	80	115	54,1
КС 30000-11	30	10,5	0,27	150	250	118,8
КСВ 37500-11	37,5	10,5				147
КСВ 75000-11	75	11	0,194			246

Note. The compensators of types KS have air cooling, while those of types KSV - surface hydrogen.

Key: (1). Type of the synchronous condenser. (2). Nominal power, MVA. (3). Nominal voltage, kV. (4). Ultratransitory inductive reactance. (5). Agent. (6). power, kW. (7). voltage, in. (8). Total weight, t.

P-4.1. Standard double wound transformers to high voltage 6, 10, 35 and 110 kV.

(1) Тип	$u_к$, %	(2) Габаритные размеры, мм			(3) Полный вес, т	(4) Стоимость, тыс. руб.
		(5) длина	(6) ширина	(7) высота		
ТМ-10/6	5,5	920	780	1 110	0,345	—
ТМ-20/6	5,5	920	780	1 110	0,365	1,4
ТМ-20/10	5,5	1 200	600	1 335	0,525	1,8
ТМ-50/6	5,5	1 050	800	1 490	0,640	1,8
ТМ-50/10	5,5	1 270	800	1 490	0,700	2,3
ТМ-100/6	5,5	1 170	820	1 480	0,890	2,57
ТМ-100/10	5,5	1 300	870	1 550	1,000	3,0
ТМ-100/35	6,5	1 400	1 085	1 800	1,500	4,4
ТМ-180/6	5,5	1 620	1 010	1 490	1,280	3,85
ТС-180/10	5,5	2 420	1 130	2 040	1,860	14,00
ТМ-180/10	5,5	1 550	880	1 670	1,360	4,10
ТМ-180/35	6,5	2 310	1 020	2 065	2,100	5,95
ТМ-320/6	5,5	1 830	1 170	1 670	1,730	5,10
ТС-320/10	5,5	2 420	1 130	2 040	2,450	18,25
ТМ-320/10	5,5	1 680	1 020	1 760	1,780	5,40
ТМ-320/35	6,5	2 260	1 350	2 140	2,730	8,48
ТС-560/10	5,5	2 500	1 245	2 200	3,75	27,50
ТМ-560/10	5,5	2 420	1 360	2 210	3,04	8,48
ТМ-560/35	6,5	2 475	1 240	2 450	3,95	11,00
ТС-750/10	5,5	2 520	1 290	2 500	4,68	34,50
ТМ-750/10	5,5	2 560	1 490	2 600	4,69	11,90
ТМ-1000/10	5,5	2 560	1 620	3 030	5,46	14,90
ТМ-1000/35	6,5	2 790	1 680	3 055	6,38	16,90
ТМ-1800/10	5,5	2 940	1 750	3 450	8,91	23,80
ТМ-1800/35	6,5	2 940	1 750	3 450	9,07	24,50
ТМ-3200/10	5,5	4 150	2 500	4 000	13,40	31,40
ТМ-3200/35	7,0	4 150	2 500	4 000	13,50	33,70
ТМ-5600/10	5,5	4 250	3 700	4 000	19,16	44,40
ТМ-5600/35	7,5	4 250	3 700	4 000	19,40	48,50
ТМГ-5600/110	10,5	5 000	4 390	4 690	35,3	84,0
ТМ-7500/35	7,5	5 050	3 740	4 140	22,8	58,0
ТМГ-7500/110	10,5	5 500	4 400	4 955	40,5	96,0
ТД-10000/35	7,5	3 800	3 800	4 235	25,0	69,2
ТДГ-10000/110	10,5	5 360	4 400	5 105	40,0	110,0
ТД-15000/35	8,0	4 270	3 900	4 615	28,1	88,0
ТДГ-15000/110	10,5	5 450	4 450	5 225	50,3	135,0
ТД-20000/35	8,0	4 470	3 900	5 030	37,0	104,0
ТДГ-20000/110	10,5	5 600	4 450	5 360	59,0	163,0
ТД-31500/35	8,0	4 650	4 140	5 500	54,0	160,0
ТД-40500/35	8	6 000	4 300	6 230	66	—
ТДГ-31500/110	10,5	6 350	4 570	5 945	70,0	198,0
ТДГ-40500/110	10,5	6 550	4 670	6 200	90,0	244,0
ТДГ-60000/110	10,5	7 300	4 750	7 200	115,8	328,4
ОДГ-10500/110	10,5	4 000	4 400	5 150	31,3	95,0
ОДГ-13500/110	10,5	4 200	4 500	5 450	36,5	112,0
ОДГ-20000/110	10,5	5 300	4 550	5 700	45,6	142,0
ОДГ-40000/110	10,5	6 500	4 450	6 800	76,0	245,0

Key: (1). Type. (2). Overall dimensions, mm. (3). Gross weight, t. (4). Cost/value. of thousand of rub. (5). length. (6). width. (7). height.

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P-4.2. Standard triple-wound transformers to high voltage 110 kV.

(1) Тип	(2) $u_к$, % между обмотками	(3) Габаритные размеры, мм			(4) Полный вес, т	(5) Стоимость, тыс. руб.
		(6) длина	(7) ширина	(8) высота		
ТМТГ-5600/110	В — С — 17%	5 420	4 540	5 080	43,0	117,0
ТМТГ-7500/110	(10,5%)	5 770	4 590	5 210	48,6	140,0
ТДТГ-10000/110	В — Н — 10,5%	5 440	4 570	5 205	48,5	162,0
ТДТГ-15000/100	(17%)	5 835	4 700	5 400	60,8	195,0
ТДТГ-20000/110	С — Н — 6%	6 000	4 700	5 555	71,0	228,0
ТДТГ-31500/110	(6%)	6 500	4 850	6 075	92,0	308,3
ТДТГ-40500/110	В — С — 17%	6 800	4 850	6 515	109,5	320,0
ТДТГ-60000/110	(10,5%)	8 120	5 130	7 665	144,0	438,0
ОДТГ-10500/110	В — Н — 10,5%	4 020	4 590	5 400	36,7	128,0
ОДТГ-13500/110	(17%)	4 300	4 690	5 465	45,0	146,0
ОДТГ-20000/110	С — Н — 6%	4 800	4 790	5 745	56,0	185,0
ОДТГ-40000/110	(6%)	6 700	4 700	6 970	91,4	296,0

Notes: 1. For the nominal power of triple-wound transformer starts the power of its most powerful/thick winding.

2. Voltage of short circuiting between each pair of windings in triple-wound transformers is related to nominal power of transformer.

Key: (1). Type. (2). between windings. (3). Overall dimensions, mm. (4). Gross weight, t. (5). Cost/value, thousand of rub. (6). length. (7). width. (8). height.

Relationship/ratio of the power of the windings of triple-wound

transformers.

(1) Мощность обмотки, % номинальной		
ВН	*СН*	*НН*
100	100	100
100	100	67
100	67	100

Key: (1). Power of winding, o/o nominal.

P-4.3. Powerful/thick transformers 110-500 kV.

(1) Тип	$u_к$, %	(2) Габаритные размеры, *мм*			(6) Полный вес, *т*	(7) Стоимость, тыс. руб.
		(3) длина	(4) ширина	(5) высота		
ТДНГ-10000/110	14	4 940	4 940	6 660	53	189
ТДТНГ-10000/110	—	5 100	5 180	6 440	70	236
ТДНГ-15000/110	10,7	4 730	4 930	6 490	60	231
ТДТНГ-15000/110	*ВС* — 10,5 *ВН* — 17,6 *СН* — 6	—	—	—	74	274
ТДНГ-20000/110	11	4 800	4 970	7 080	70	256
ТДТНГ-20000/110	*ВС* — 12 *ВН* — 20 *СН* — 6,5	5 880	5 270	6 890	85	323
ТДНГ-31500/110	12	6 300	5 110	7 400	92	330
ТДТНГ-31500/110	*ВС* — 17,5 (10,5) *ВН* — 10,5 (17) *СН* — 6,3 (6)	6 800	5 600	7 600	123	397
ТДТНГ-40500/110	—	8 583	5 275	7 700	129	474
ТЦТНГ-40500/110	—	—	—	—	107	445
ТДГ-45000/110	10,5	6 960	4 970	6 350	90	292
ТДТГ-45000/110	10,5	—	—	—	110	365
ТДГ-70000/110	13	8 200	5 500	7 500	129	452
ТДГ-75000/110	10,5	7 850	5 540	7 400	126	—
ТДГ-90000/110	10,5	6 900	4 260	7 200	113	—
ТДЦГ-120000/110	10,25	7 700	4 500	7 120	125	—
ТДЦГ-180000/110	10,5	8 470	5 100	7 300	173	—
ТДЦГ-240000/110	10,5	9 750	5 300	6 350	232	—
ОДГ-50000/110	10,5	6 050	4 690	7 420	85	335
ТДГ-10000/150	14	6 590	4 710	6 460	61	—
ТДГ-15000/150	11,5	6 630	4 800	6 525	72	243
ТДГ-20000/150	—	—	—	—	82	275
ТДТГ-20000/150	—	—	—	—	110	366
ТДГ-31500/150	12,5	7 680	5 070	6 850	111	336
ТДТГ-31500 150	*ВС* — 18 *ВН* — 12,5 *СН* — 5,5	8 020	5 200	7 310	131	436
ТДГ-65000/150	13	8 670	5 570	7 670	154	467
ТЦГ-70000/150	14	6 300	3 800	7 050	122	513

Page 387. Continuation table P-4.3.

Тип	$u_к$, %	Габаритные размеры, мм			Полный вес, т	Стоимость, тыс. руб.
		длина	ширина	высота		
ОДТГ-15000/150	—	—	—	—	70	257
ОДТГ-20000/150	11	4 620	4 750	6 340	64	218
ОДГ-30000/150	10,5	—	—	—	—	327
ОДГ-20000/220	13	5 380	4 900	7 940	85	275
ОМГ-20000/220	13	7 600	5 730	7 780	126	—
ОДТГ-20000/220	ВС — 14 (22) ВН — 22 (14) СН — 8 (8)	7 900	5 860	7 340	116	380
ОДГ-25000/220	13	5 700	4 900	7 900	94	308
ОДГ-30000/220	15	5 700	4 950	7 610	96	331
ОДТГ-33333/220	ВС — 14 (23) ВН — 23 (14) СН — 8 (8)	6 300	6 320	8 000	137	462
ОДГ-33333/220	—	5 900	4 150	7 700	100	325
ОЦТГ-33333/220	—	6 424	3 680	8 250	134	—
ОДГ-40000/220	13	6 820	5 200	8 005	112	406
ОДТГ-40000/220	ВС — 22 (13,5) ВН — 13,5 (22) СН — 8 (8)	7 940	6 230	8 215	151	566
ОДГ-46000/220	12	7 700	5 430	7 400	132	445
ОДТГ-46667/220	ВС — 21 (13) ВН — 13 (21) СН — 8 (8)	7 940	6 230	8 175	156	—
ОДГ-50000/220	12	6 900	5 500	7 865	130	—
ОДГ-60000/220	14	7 750	5 500	8 000	136	415
ОДТГ-60000/220	ВС — 23 (14,5) ВН — 14,5 (23) СН — 7,5 (7,5)	8 830	6 335	8 390	183	590
ОЦГ-82500/220	—	—	—	—	—	—
ОЦТГ-82500/220	—	8 500	4 350	8 250	200	846
ОДЦГ-160000/220	—	10 500	6 900	8 000	260	—
ТДГ-10000/220	—	—	—	—	—	—
ТДТГ-10000/220	—	—	—	—	—	—
ТДГ-15000/220	—	—	—	—	—	—
ТДТГ-15000/220	—	—	—	—	—	—
ТДГ-20000/220	14	—	—	—	—	—
ТДТГ-20000/220	—	—	—	—	—	230
ТДГ-31500/220	—	—	—	—	—	420
ТДТГ-31500/220	—	—	—	—	—	—
ТДГ-40500/220	14	—	—	—	—	340
ТДТГ-40500/220	—	—	—	—	—	510
ТДГ-60000/220	14	—	—	—	—	400
ТДТГ-60000/220	—	—	—	—	—	630
ТДЦГ-90000/220	12,4	—	—	—	—	560
ТДЦГ-120000/220	11,5	10 500	5 000	8 000	—	700
ТДЦГ-180000/220	12	10 700	6 250	7 000	—	1 000
ТДЦГ-240000/220	12,7	13 000	6 800	6 500	—	1 250
ТДЦГ-250000/220	11,11	17 000	7 000	8 000	379	—
ТДЦГ-360000/220	12,6	—	—	—	—	—
ОЦГ-82500/400	—	—	—	—	—	—
ОЦТГ-82500/400	—	—	—	~13 000	~450	—
ОДТГ-90000/400	ВС — 13 ВН — 18,2 СН — 5,2	11 270	7 610	12 015	335	1 530
ОЦГ-123500/400	13	10 880	4 780	11 900	297	1 600
ОЦТГ-123500/400	—	11 600	5 100	10 700	420	—
ОДЦГ-135000/500	13	11 600	6 400	10 500	—	—
ОДЦГ-250000/500	13	11 600	7 500	11 500	—	—

Key: (1). Type. (2). Overall dimensions, mm. (3). length. (4). width. (5). height. (6). Gross weight, t. (7). Cost/value, thousand of rub.

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P-4.4. Three-phase double wound transformers for its own needs of stations and substations.

(1) Номинальное высшее напряжение, кв	(2) Номинальная мощность, ква	$u_к$, %	(1) Номинальное высшее напряжение, кв	(2) Номинальная мощность, ква	$u_к$, %
3,15; 6,3	10—320	5,5	10,5; 13,8; 15,75	10 000	10
10,5	20—1 000	5,5	13,8	15 000	8,2
3,15, 6,3	560—1 000	8	10,5; 13,8;	20 000	8,3
6,3; 10,5	1 800—3 200	8	15,75; 18; 20		
10,5, 15,75	5 600	8	15,75; 18	31 500	10,5
10,5; 13,8	7 500	10			

Key: (1). Nominal high voltage, kV. (2). Nominal power, kVA.

P-5. Autotransformers (according to data of Moscow and Zaporozh'ye transformer plants, Electroheat-plan and Leningrad department of Gidroenergoproyekt).

(1) Тип	(2) Мощность обмоток, *Мва*	(3) Напряжение холостого хода, *кв*	(4) $u_к$, %, отнесенное к мощности обмотки ВН, %			(5) Габаритные размеры, *мм*			(6) Полный вес, *т*
			ВН—СН	*ВН—НН*	*СН—НН*	(7) длина	(8) ширина	(9) высота	
ОДТГА-$\frac{40000}{220}$	40/40/20	$\frac{220}{\sqrt{3}}/\frac{100}{\sqrt{3}}/11$	9—11	32—38	18—22	6 300	5 250	7 350	86
ОДТГА-$\frac{46667}{220}$	47/80/80	$13,8/\frac{121}{\sqrt{3}}/\frac{242}{\sqrt{3}}$	14—16	9—12	14—17	—	—	—	—
ОДТГА-$\frac{53500}{220}$	53,5/107/107	$15,75/\frac{121}{\sqrt{3}}/\frac{242}{\sqrt{3}}$	13	12	16	7 800	6 600	8 600	160
ОДТГА-$\frac{60000}{220}$	60/60/30	$\frac{220}{\sqrt{3}}/\frac{110}{\sqrt{3}}/11$	10	32	20	6 300	6 320	8 000	132
ОДТГА-$\frac{69000}{220}$	69/138/138	$13,8/\frac{121}{\sqrt{3}}/\frac{242}{\sqrt{3}}$	14—16	9—12	14—17	—	—	—	—
ОДТГА-$\frac{80000}{220}$	80/80/40	$\frac{220}{\sqrt{3}}/\frac{110}{\sqrt{3}}/11$	10,5	36	23	7 860	5 500	7 570	131
ОДТГА-$\frac{90000}{500}$	90/90/45	$\frac{500}{\sqrt{3}}/\frac{110}{\sqrt{3}}/11$	12	20,4	17,2	10 500	6 660	10 400	—
ОДТГА-$\frac{120000}{220}$	120/120/60	$\frac{220}{\sqrt{3}}/\frac{121}{\sqrt{3}}/11$	10,1	32	20	8 830	6 335	8 690	183
ОДТГА-$\frac{120000}{220}$	120/120/60	$\frac{220}{\sqrt{3}}/\frac{121}{\sqrt{3}}/38,5$	8,32	—	—	—	—	—	—
ТДТГА-$\frac{30000}{220}$	30/30/15	220/110/11	9,3	29,1	18,8	—	—	—	90
ТДТГА-$\frac{60000}{220}$	60/60/30	220/110/11	8,9	30,6	19,4	—	—	—	155
ТДТГА-$\frac{90000}{220}$	90/90/45	220/110/11	7,97	27,34	17,4	—	—	—	200
ТДТГА-$\frac{120000}{220}$	120/120/60	220/110/11	10,55	37,2	23,5	—	—	—	205
ТДТГА-$\frac{180000}{150}$	180/180/25	150/110/11	—	—	—	11 500	6 200	6 645	155

Key: (1). Type. (2). Power of windings, MVA. (3). Open-circuit voltage, kV. (4). referred to power of winding VN, o/o. (5). Overall dimensions, mm. (6). total weight, t. (7). length. (8). width. (9). height.

P-6. Scale of rated currents.

For electrical apparatuses and bushings GOST 6827-54 is established/installed the following scale of rated currents: 1; 2.5; 4; 6; 10; 15; 25; 40; 60; 100; 150 (200); by 250; 300; 400; 600 (800); 1000; 1500; 2000; 2500; 3000; 4000; 5000; 6000; 8000; 10000; 12000; 15000 a.

Notes: 1. In brackets are shown the values of currents, not recommended with GOST to wide application.

2. Scale of nominal primary currents of current transformers is given in note 1 to Table P-17.

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P-7. Fundamental characteristics of reactors.

P-7.1. Reactors concrete with copper winding.

(1) На номинальное напряжение 6 кв

(2) Тип реактора	(3) Номинальные потери на фазу, квт	(4) Ток электродинамической устойчивости (амплитудное значение) $i_{макс}$, ка	(5) Величина, характеризующая термическую устойчивость $I_t\sqrt{t}$, ка·сек$^{1/2}$
РБ6-150-3	1,18	9,74	9
4	1,44	9,55	8,25
5	1,63	7,65	7,5
6	1,87	6,40	6,75
8	2,16	4,8	6
10	2,96	3,82	6
РБ6-200-3	1,32	13	12
4	1,68	12,75	11
5	2,0	10,2	10
6	2,0	8,5	9
8	2,50	6,4	8
10	2,86	5,1	8
РБ6-300-3	1,73	19,5	18
4	2,34	19,1	16,5
5	2,49	15,3	15
6	3,02	12,8	13,5
8	3,46	9,55	12
10	3,79	7,65	12
РБ6-400-3	2,15	26	24
4	2,65	25,5	22
5	2,97	20,4	20
6	3,82	17	18
8	4,2	12,75	16
10	4,97	10,2	16
РБ6-500-3	2,86	32,5	30
4	2,86	31,9	27,5
5	3,75	25,5	25
6	3,75	21,2	22,5
8	4,55	15,9	20
10	5,57	12,75	20
РБ6-600-3	2,46	39	36
4	3,15	38,2	33
5	3,79	30,6	30
6	4,71	25,5	27
8	5,77	19,1	24
10	6,24	15,3	24
РБ6-750-3	2,95	48,75	45
4	3,98	47,8	47,25
5	4,38	38,2	37,5
6	4,82	31,9	33,75
8	6,46	23,9	30
10	7,1	19,1	30
РБ6-1000-4	4,07	63,8	55
5	4,84	51	50
6	5,05	42,5	45
8	5,9	31,9	40
10	7,34	25,5	40
РБ6-1500-5	6,64	76,5	75
6	7,05	63,8	67,5
8	9,4	47,8	60
10	10,6	38,3	60
РБ6-2000-6	8,02	85	90
10	11,38	51	80

(1) На номинальное напряжение 10 кв

(2) Тип реактора	(3) Номинальные потери на фазу, квт	(4) Ток электродинамической устойчивости (амплитудное значение) $i_{макс}$, ка	(5) Величина, характеризующая термическую устойчивость $I_t\sqrt{t}$, ка·сек$^{1/2}$
РБ10-150-3	1,68	9,74	9
4	1,94	9,55	8,25
5	2,19	7,65	7,5
6	2,62	6,4	6,75
8	3,26	4,8	6
РБ10-200-3	2,1	17	12
4	2,23	10,2	11
5	2,52	10,2	10
6	2,86	8,5	9
8	3,45	6,88	8
РБ10-300-3	2,4	25,5	18
4	3,02	19,1	16,5
5	3,42	15,3	15
6	3,97	12,8	12
8	4,83	9,55	12
РБ10-400-3	2,79	26	24
4	—	25,5	22
5	4,29	20,4	20
6	4,99	17	18
8	5,75	12,75	16
РБ10-500-3	3,13	32,5	30
4	3,82	31,9	27,5
5	4,54	25,5	25
6	5,58	21,2	22,5
8	6,44	15,9	20
РБ10-600-3	3,56	39	36
4	4,45	38,2	33
5	5,66	30,6	30
6	6,24	25,5	27
8	7,79	19,1	24
10	8,72	15,3	24
РБ10-750-5	5,86	38,2	37,5
6	6,89	31,9	33,75
8	8,61	23,9	30
РБ10-1000-6	6,91	42,5	45
8	8,99	31,9	40
10	10	25,5	40
РБ10-1500-6	10,35	63,8	67,5
8	12,23	47,8	60
10	13,61	38,2	60
РБ10-2000-6	—	85	90
8	17,01	58,8	80
10	17,6	51	80

Note. In a designation of the type of reactor the first numeral indicates its nominal voltage (kV), the second - rated current (a), the third - inductive reactance in percentages (x_p%).

Key: (1). To nominal voltage 6 kV. (2). Type of reactor. (3). Nominal losses to phase, kW. (4). Current of electrodynamic stability (amplitude value). (5). Value, which characterizes thermal resistance $I_t\sqrt{t}$, kA•s$^{1/2}$.

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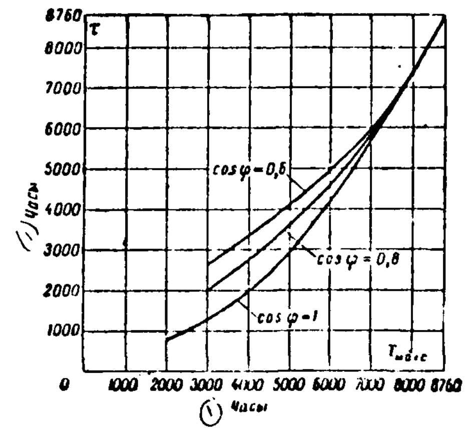
P-7.2. Reactors concrete with aluminum winding.

(1) На номинальное напряжение 6 кв			
(2) Тип реактора	(3) Номинальные потери на фазу, квт	(4) Ток электродинамической устойчивости (амплитудное значение) $i_{макс}$, ка	(5) Величина, характеризующая термическую устойчивость $I_t\sqrt{t}$, ка·сек$^{1/2}$
РБА6-150-4	1,431	9,55	8,25
5	1,575	7,65	7,5
6	2,033	6,4	6,75
8	2,216	4,8	6,0
10	2,592	3,82	6,0
РБА6-200-4	1,835	12,75	11,0
5	2,48	10,2	10,0
6	2,69	8,5	9,0
8	3,2	6,4	8,0
10	3,67	5,1	8,0
РБА6-300-4	2,42	19	14
5	2,72	15	15
6	3,26	12,8	13,5
8	3,53	9,5	15
10	4,492	7,65	12
РБА6-500-4	3,175	31,9	27,5
5	3,2	25,5	25,0
6	4,09	21,2	22,5
8	4,405	15,9	20,0
10	5,44	12,75	20,0
РБА6-600-4	3,172	38,2	33,0
5	3,9	30,0	30,6
6	4,45	25,4	28,2
8	6,627	19,1	24,0
10	7,37	15,3	24,0

(1) На номинальное напряжение 10 кв			
(2) Тип реактора	(3) Номинальные потери на фазу, квт	(4) Ток электродинамической устойчивости (амплитудное значение) $i_{макс}$, ка	(5) Величина, характеризующая термическую устойчивость $I_t\sqrt{t}$, ка·сек$^{1/2}$
РБА10-150-4	2,0	9,55	8,25
5	2,26	7,65	7,5
6	2,56	6,38	6,75
8	3,069	4,8	6,0
РБА10-200-4	2,325	10,2	11,0
5	2,21	10,2	10,0
6	3,56	8,2	9,0
8	3,77	6,88	8,0
РБА10-300-4	3,65	17,0	14,5
5	3,22	15,3	15,0
6	4,02	12,8	12,0
8	4,697	9,55	12,0
РБА10-500-4	4,44	31,9	27,5
5	5,48	25,5	25,0
6	5,9	21,2	22,5
8	7,645	15,9	20,0
РБА10-600-5	5,325	30,6	30,0
6	7,93	25,4	27,0
8	8,85	19,1	24,0
10	10,0	15,3	24,0

Key: (1). To nominal voltage 6 kV. (2). Type of reactor. (3). Nominal losses to phase, kW. (4). Current of electrodynamic stability (amplitude value). (5). Value, which characterizes thermal resistance $I_t\sqrt{t}$, kA•s$^{1/2}$.

P-8. Dependence of time of losses τ on demand time by maximum load $T_{макс}$



Key: (1). hours.

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P-9. Fundamental characteristics of support and partition insulators.

(1) Опорные изоляторы		
(3) Тип	(4) Номинальное напряжение, кв	(5) Разрушающая механическая нагрузка на изгиб, кГ
(7) *Для внутренней установки*		
ИОА-500	0,5	250
ОМА-6, ОА-6	6	
ОМА-10, ОА-10	10	375
ОА-35	35	
ОМБ-6, ОБ-6	6	
ОМБ-10, ОБ-10	10	750
ОБ-35	35	
ОВ-10	10	1 250
ОМД-10, ОД-10	10	2 000
ОМД-20, ОД-20	20	
ОМЕ-20	20	3 000
(8) *Для наружной установки*		
ШН-6	6	375
ШН-10	10	500
ИШД-10	10	2 000
ШТ-35	35	1 250
ИШД-35	35	2 000
3ШТ-35	110	325
4ИШД-35	154	325
5ИШД-35	220	250
СТ-6	6	
СТ-10	10	
СТ-20	20	
СТ-35	35	600
СТ-110	110	400
КО-10	10	2 000
КО-400 (12) (колонка из 12 изоляторов)	400	1 000

(2) Проходные изоляторы			
(3) Тип	(4) Номинальное напряжение, кв	(6) Номинальный ток, а	(5) Разрушающая механическая нагрузка на изгиб, кГ
(9) *Для внутренней установки*			
ПА-6	6	200, 400	375
ПБ-6	6	400, 600, 1 000, 1 500	
ПБ-10	10	200, 400, 600, 1 000, 1 500	750
ПБ-35	35	400, 600, 1 000, 1 500	
ПВ-6	6	(9) 1 000, 1 500, 2 000	1 250
ПВ-10	10		
ИПШ-I-10	10	См. примечание	2 000
ИПШ-II-10	10	(10) То же	3 000
ИПШ-III-10	10	» »	4 000
ПШД-20	20	» »	3 000
ИПШ-III-20/3000	20	3 000	2 000
ИПШ-III-20/6000	20	6 000	2 000
(11) *Линейные выводы*			
ПНБ-6	6	400, 600, 1 000, 1 500	750
ПНБ-10	10		
ПНБ-35	35		
ПНВ-10	10	1 000, 1 500, 2 000	
ПНВ-20	20	2 000, 2 500, 3 000, 4 000	1 250
ИПШ-III-35/3000	35	3 000	2 000
ИПШ-III-35/6000	35	6 000	2 000

Note. Passage busbar/tire insulators are adapted for the flat/plane busbars/tires, comprised of 1-4 strips to the phase (in packet) of the following sizes/dimensions:

insulator of the type IPSh-1-10 - 60x6 - 60x8 mm inclusively;

insulators of types IPSh-11-10 and PShD-20 - 60x8 - 80x10 mm inclusively;

insulator of the type IPSh-Sh-1) - 80x10 - 100x10 mm inclusively.

Key: (1). Stand-off insulators. (2). Bushings. (3). Type. (4). Nominal voltage, kV. (5). Destructive mechanical bending load, kgf. (6). Rated current, a. (7). For internal installation. (8). For external installation. (9). See note. (10). Then. (11). Linear conclusions/derivations. (12). column of 12 insulators.

P-10. Long let-go currents of load on naked busbars/tires and wires/conductors with alternating current 50 Hz, at permissible heating temperature by 70°C and at temperature of air of 25°C.

P-10.1. Busbars/tires copper and aluminum rectangular cross sections painted.

(1) Размеры шин, мм	(2) Сечение одной полосы, мм²	(3) Вес 1 м одной полосы, кг		(4) Допускаемые токи, а							
				1 полоса (5)		2 полосы (6)		3 полосы (6)		4 полосы (6)	
		(7) Медь	(8) Алюминий	(7) Медь	(8) Алюминий	(7) Медь	(8) Алюминий	(7) Медь	(8) Алюминий	(7) Медь	(8) Алюминий
15×3	45	0,400	0,122	210	165	—	—	—	—	—	—
20×3	60	0,534	0,162	275	215	—	—	—	—	—	—
25×3	75	0,668	0,203	340	265	—	—	—	—	—	—
30×4	120	1,066	0,324	475	365	—	—	—	—	—	—
40×4	160	1,424	0,432	625	480	—	—	—	—	—	—
40×5	200	1,780	0,540	700	540	—	—	—	—	—	—
50×5	250	2,225	0,675	860	665	—	—	—	—	—	—
50×6	300	2,670	0,810	955	740	—	—	—	—	—	—
60×6	360	3,204	0,972	1 125	870	1 740	1 350	2 240	1 720	—	—
60×8	480	4,272	1,295	1 320	1 025	2 160	1 680	2 790	2 180	—	—
60×10	600	5,340	1,620	1 475	1 155	2 560	2 010	3 300	2 650	—	—
80×6	480	4,272	1,295	1 480	1 150	2 110	1 630	2 720	2 100	—	—
80×8	640	5,698	1,728	1 690	1 320	2 620	2 049	3 370	2 620	—	—
80×10	800	7,12	2,160	1 900	1 480	3 100	2 410	3 990	3 100	—	—
100×6	600	5,340	1,620	1 810	1 425	2 470	1 935	3 170	2 500	—	—
100×8	800	7,120	2,160	2 080	1 625	3 069	2 391	3 930	3 059	—	—
100×10	1 000	8,900	2,700	2 310	1 820	3 610	2 860	4 650	3 650	5 300	4 150
120×8	960	8,460	2,600	2 400	1 900	3 400	2 650	4 340	3 380	—	—
120×10	1 200	10,650	3,245	2 650	2 070	4 100	3 200	5 200	4 100	5 900	4 650

Note. Let-go currents are given for the horizontal padding of busbars/tires with the agreement of the large face of strip with vertical plane. With the horizontal padding of busbars/tires and the agreement of the large face of strip with horizontal plane let-go currents should be decreased by 5o/o for strips in width to 60 mm inclusively and by 8o/c for the strips of larger width.

Key: (1). Sizes/dimensions of busbars/tires, mm. (2). Section of one strip, mm^2. (3). Weight of 1 m of one strip, kg. (4). Let-go currents, a. (5). strip. (6). strip. (7). Copper. (8). Aluminum.

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P-10.2. Busbars/tires steel of rectangular cross section painted.

(1) Размеры шин, мм	(2) Сечение полосы, мм²	(3) Вес 1 м полосы, кг	(4) Допускаемые токи, а	(1) Размеры шин, мм	(2) Сечение полосы, мм²	(3) Вес 1 м полосы, кг	(4) Допускаемые токи, а
16×2,5	40	0,31	55	90×3	270	2,10	275
20×2,5	50	0,39	60	100×3	300	2,35	305
25×2,5	62,5	0,49	70	20×4	80	0,63	70
20×3	60	0,47	65	22×4	88	0,69	75
25×3	75	0,59	80	25×4	100	0,79	85
30×3	90	0,71	95	30×4	120	0,94	100
40×3	120	0,94	125	40×4	160	1,26	130
50×3	150	1,18	155	50×4	200	1,57	165
60×3	180	1,41	185	60×4	240	1,88	195
70×3	210	1,65	215	70×4	280	2,2	225
75×3	225	1,77	230	80×4	320	2,51	260
80×3	240	1,88	245	90×4	360	2,8	290
				100×4	400	3,14	325

Note. See the note to Table P-10.1.

Key: (1). Sizes/dimensions of busbars/tires, mm. (2). Section of strip, mm². (3). Weight of 1 m of strip, kg. (4). Let-go currents, a.

P-10.3. Busbars/tires copper, aluminum and steel round and ribbed sections painted.

(1) Шины круглые			(2) Медные трубы		(3) Трубы алюминиевые		(4) Трубы стальные		
(7) Диаметр, мм	(5) Допускаемые токи, а		(10) Внутренний и наружный диаметры, мм	(11) Допускаемые токи, а	(10) Внутренний и наружный диаметры, мм	(11) Допускаемые токи, а	(6) Диаметры труб, мм		(14) Допускаемые токи на трубы без разреза, а
	(8) Медные	(9) Алюминиевые					(12) внутренний, дюймы	(13) наружный, мм	
6	155	120	12/15	340	13/16	295	1/4	13,5	75
7	195	150	14/18	460	17/20	345	3/8	17,0	90
8	235	180	16/20	505	18/22	425	1/2	21,35	118
10	320	245	18/22	555	27/30	500	3/4	26,75	145
12	415	320	20/24	600	26/30	575	1	33,50	180
14	505	390	22/26	650	25/30	640	1 1/4	42,45	220
15	565	435	25/30	830	36/10	765	1 1/2	48,00	255
16	610	475	29/34	925	35/40	850	2	60,00	320
18	720	560	35/40	1 100	40/45	935	2 1/2	75,50	390
19	780	605	40/45	1 200	45/50	1 040	3	88,50	455
20	835	650	45/50	1 330	50/55	1 145	4	114	670/770*
21	900	695	49/55	1 580	54/60	1 340	5	137	800/890*
22	955	740	53/60	1 860	64/70	1 545	6	164	900/1 000*
25	1 140	885	62/70	2 295	74/80	1 770			
27	1 270	980	72/80	2 610	72/80	2 035			
28	1 325	1 025	75/85	3 070	75/85	2 400			
30	1 450	1 120	90/95	2 460	90/95	1 925			
35	1 770	1 370	93/100	3 060	90/100	2 840			
38	1 960	1 510							
40	2 080	1 610							
42	2 200	1 700							
45	2 380	1 850							

Key: (1). Busbars/tires are circular. (2). Copper pipes. (3). Pipes (aluminum. (4). Pipes (steel. (5). Let-go currents, a. (6). Diameters of pipes, mm. (7). Diameter, mm. (8). Copper. (9). Aluminum. (10). Internal and outside diameters, mm. (11). Let-go currents, a. (12). internal, inches. (13). external, mm. (14). Let-go currents to pipes without size/dimension, a.

FOOTNOTE [1]. For pipes with longitudinal section. ENDFOOTNOTE.

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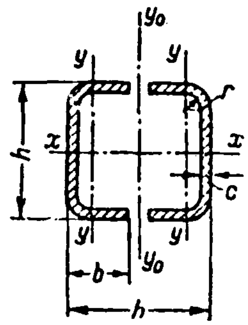
P-10.4. Busbars/tires copper and aluminum box sections painted [3-6 and 10-3].

(1) Размеры, мм				(2) Сечение одной шины, $мм^2$	(3) Моменты сопротивления сечения, $см^3$			(4) Допускаемые токи на две шины, а	
					(5) одной шины		(6) двух сращенных шин относительно оси y_0-y_0 W_{y_0}		
h	b	c	r		(7) относительно оси $x-x$ W_x	(7) относительно оси $y-y$ W_y		(8) медные	(9) алюминиевые
75	35	4	6	520	10,1	2,52	23,7	2 730	—
75	35	5,5	6	695	14,1	3,17	30,1	3 250	2 670
100	45	4,5	8	775	22,2	4,51	48,6	3 620	2 820
100	45	6	8	1 010	27	5,9	58	4 300	3 500
125	55	6,5	10	1 370	50	9,5	100	5 500	4 640
150	65	7	10	1 785	74	14,7	167	7 000	5 650
175	80	8	12	2 440	122	25	250	8 550	6 430
200	90	10	14	3 435	193	40	422	9 900	7 550
200	90	12	16	4 040	225	46,5	490	10 500	8 830
225	105	12,5	16	4 880	307	66,5	615	12 500	10 300
250	115	12,5	16	5 450	360	81	824	—	10 800



Key: (1). Sizes/dimensions, mm. (2). Section of one busbar/tire, mm². (3). Moduli of section, cm³. (4). Let-go currents to two busbars/tires, a. (5). one busbar/tire. (6). two joined busbars/tires relative to axis. (7). relative to axis. (8). copper. (9). aluminum.

P-10.5. Wires/conductors naked copper, aluminum, steel-aluminum and steel with padding outdoors.

(1) Медные			(2) Алюминиевые			(3) Сталеалюминиевые			(4) Стальные		
(5) Марка провода	(6) Наружный диаметр провода, мм	(7) Допускаемые токи, а	(5) Марка провода	(6) Наружный диаметр провода, мм	(7) Допускаемые токи, а	(5) Марка провода	(6) Наружный диаметр провода, мм	(7) Допускаемые токи, а	(5) Марка провода	(6) Наружный диаметр провода, мм	(7) Допускаемые токи, а
М-4	2,2	50	А-10	—	75	АС-16		105	ПСО-3	3	23
М-6	2,7	70	А-16	5,1	105	АС-25		135	ПСО-3,5	3,5	26
М-10	3,5	95	А-25	6,3	135	АС-35	8,3	170	ПСО-4	4	30
М-16	5,1	130	А-35	7,5	170	АС-50	9,9	220	ПСО-5	5	35
М-25	6,3	180	А-50	9,0	215	АС-70	11,7	275	ПС-25	5,6	60
М-35	7,5	220	А-70	10,6	265	АС-95	13,9	335	ПС-35	7,8	75
М-50	9,0	270	А-95	12,4	325	АС-120	15,3	380	ПС-50	9,2	90
М-60	10,4	315	А-120	14,0	375	АС-150	17,0	445	ПС-70	11,5	125
М-70	10,6	340	А-150	15,8	440	АС-185	19,1	515	ПС-95	12,6	140
М-95	12,4	415	А-185	17,4	500	АС-240	21,5	610			
М-120	14,0	485	А-240	20,1	610	АС-300	24,4	700			
М-150	15,8	570	А-300	22,2	680	АС-400	27,8	800			
М-185	17,5	615	А-400	25,6	830	АСО-332	25,2	745			
М-240	20,0	770	А-500	29,1	950	АСО-480	30,2	925			
М-300	22,2	890	А-625	32,5	1 140	АСУ-300	25,2	710			
М-400	25,6	1 085				АСУ-400	29,3	865			
МП-240	30	950									
МП-300		1 050									

Key: (1). Copper. (2). Aluminum. (3). Steel-aluminum. (4). Steel. (5). stamp of wire/conductor. (6). Outside diameter of wire/conductor, mm. (7). Let-go currents, a.

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P-11. Lonj let-go currents of load on power cables.

P-11.1. Cables to voltayes 1-10 kV with copper and aluminum veins/strands with paper impregnated insulation in lead or aluminum shell, laid in it swooned at temperature of soil of 15°C.

(2) Номинальное сечение жилы, мм²	(7) Допускаемые токи, а					
	(3) Одножильные кабели 1 кв	(4) Двухжильные кабели 1 кв	(5) Трехжильные кабели с поясной изоляцией			(6) Четырехжильные кабели 1 кв
			(7) до 3 кв	(8) 6 кв	(8) 10 кв	
	(9) Максимальная допускаемая температура жилы кабеля, °C					
	80°	80°	80°	65°	60°	80°
1,5	45	35	30/—	—	—	—
2,5	60	45	40/31	—	—	—
4	80	60	55/42	—	—	50/—
6	105	80	70/55	—	—	60/46
10	140	105	95/75	80/60	—/55	85/65
16	175	140	120/90	105/80	95/75	115/90
25	235	185	160/125	135/105	120/90	150/115
35	285	225	190/145	160/125	150/115	175/135
50	360	270	235/180	200/155	180/140	215/165
70	410	325	285/220	245/190	215/165	265/200
95	520	380	340/260	295/225	265/205	310/240
120	595	435	390/300	310/260	310/240	350/—
150	675	500	435/335	390/300	355/275	395/—
185	755	—	490/380	440/340	400/310	450/—
240	880	—	570/440	510/390	460/355	—
300	1 000	—	—	—	—	—
400	1 220	—	—	—	—	—
500	1 400	—	—	—	—	—
625	1 520	—	—	—	—	—
800	1 700	—	—	—	—	—

Notes: 1. In numerator are shown the let-go currents the cables with copper veins/strands, while in denominator - to cables with aluminum veins/strands.

2. Let-go currents for single-core cables are given for their work on direct current.

Key: (1). Let-go currents, a. (2). Nominal section of vein/strand, mm². (3). Single-core cables 1 kV. (4). Two-core cables 1 kV. (5). Three-strand belted cables. (6). Four-wire cables 1 kV. (7). to 3 kV. (8). kV. (9). Maximum permissible temperature of cable core, °C.

P-11.2. Cables to voltages 1-10 kV with copper and aluminum veins/strands with paper impregnated isolation in lead or aluminum shell, laid in open air at temperature of air of 25°C.

(1) Номинальное сечение жилы, мм²	(2) Допускаемые токи, а					
	(3) Одножильные кабели 1 кв	(4) Двухжильные кабели 1 кв	(5) Трехжильные кабели с поясной изоляцией			(6) Четырехжильные кабели 1 кв
			(7) до 3 кв	(8) 6 кв	(8) 10 кв	
	(9) Максимальная допускаемая температура жилы кабеля, °С					
	80°	80°	80°	65°	60°	80°
1,5	30	25	18/—	—	—	—
2,5	40	30	28/22	—	—	25/—
4	55	40	37/29	—	—	35/—
6	75	55	45/35	—	—	45/35
10	95	75	60/46	55/43	50/39	60/45
16	120	95	80/60	65/50	60/46	80/60
25	160	130	105/80	90/70	85/65	100/75
35	200	150	125/95	110/85	105/80	120/95
50	245	185	155/120	145/110	135/105	145/110
70	305	225	200/155	175/135	165/130	185/140
95	360	275	245/190	215/165	200/155	215/165
120	415	320	285/220	250/190	240/185	260/—
150	470	375	330/255	290/225	270/210	300/—
185	525	—	375/290	325/250	305/235	340/—
240	610	—	430/330	375/290	350/270	—
300	720	—	—	—	—	—
400	880	—	—	—	—	—
500	1 020	—	—	—	—	—
625	1 180	—	—	—	—	—
800	1 400	—	—	—	—	—

Note. See the notes to Table P-11.1.

Key: (1). Nominal section of vein/strand, mm². (2). Let-go currents, a. (3). Single-core cables 1 kV. (4). Two-core cables 1 kV. (5). Three-strand belted cables. (6). Four-wire cables 1 kV. (7). to 3 kV. (8). kV. (9). Maximum permissible temperature of cable core, °C.

P-11.3. cables to voltages 20 and 35 kV with separately lead-coated copper veins/strands with paper impregnated isolation, laid in earth/ground at temperature of soil of 15°C and in open air at temperature of air of 25°C.

(1) Номинальное сечение жилы, мм²	(2) Допускаемые токи, а			
	(3) Трехжильные кабели			
	20 кв (4)		35 кв (4)	
	(5) Максимальная допускаемая температура жилы 50° С			
	(6) в земле	(7) в воздухе	(6) в земле	(7) в воздухе
25	110	85	—	—
35	135	100	—	—
50	165	120	—	—
70	200	150	195	145
95	240	180	235	180
120	275	205	270	205
150	315	230	310	230
185	355	265	—	265

Key: (1). Nominal section of vein/strand, mm². (2). Let-go currents, a. (3). Triple-cores cable. (4). kV. (5). Maximum permissible temperature of vein/strand of 50°C. (6). in earth/ground. (7). in air.

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P-11.4. Cables to voltaye 1 kV with paper impregnated isolation in laminar polyvinylchloride snell (brands VMB, VMBG, AVMB, AVMBG), laid in earth/grou..: at temperature of 15°C and in open air at temperature of 25°C.

(1) Номинальное сечение жилы, мм²	(2) Допускаемые токи, а							
	(3) Кабели							
	(4) с медными жилами		(5) с алюминиевыми жилами		(4) с медными жилами		(5) с алюминиевыми жилами	
	(6) трехжильные	(7) четырехжильные	(6) трехжильные	(7) четырехжильные	(6) трехжильные	(7) четырехжильные	(6) трехжильные	(7) четырехжильные
	(8) Максимальная допускаемая температура жилы 60° С							
	(9) в земле				(10) в воздухе			
6	50	40	40	30	35	35	25	25
10	70	60	55	45	45	45	35	35
16	90	80	70	60	65	65	50	50
25	125	115	95	90	85	80	65	60
35	150	135	115	105	110	105	85	80
50	190	170	145	130	135	130	105	100
70	230	205	175	160	170	155	130	120

Key: (1). Nominal section of vein/strand, mm². (2). Let-go currents, a. (3). Cables. (4). with copper veins/strands. (5). with aluminum veins/strands. (6). three-strand. (7). four-vein. (8). Maximum permissible temperature of vein/strand of 60°C. (9). in earth/ground. (10). in air.

P-11.5. Correction factors to number of working cables, which lie by row at earth/ground.

(1) Число кабелей	1	2	3	4	5	6
(2) Для расстояния в свету 100 мм	1	0,9	0,85	0,8	0,78	0,75
То же 200 мм (3)	1	0,92	0,87	0,84	0,82	0,81
То же 300 мм (3)	1	0,93	0,9	0,87	0,86	0,85

Note. During the determination of permissible design loads in a number of those lying by set of cables are not considered reserve cables.

Key: (1). Number of cables. (2). For clearance 100 mm. (3). Then 200 mm.

P-11.6. Correction factors to temperature of earth/ground and air for determining let-go currents of loads on power cables, busbars/tires and naked and insulated wires.

(1) Предельная температура среды, °С	(2) Нормированная температура проводников, °С	(3) Поправочные коэффициенты при фактической температуре среды, °С											
		−5	0	+5	+10	+15	+20	+25	+30	+35	+40	+45	+50
15	80	1,14	1,11	1,08	1,04	1,00	0,96	0,92	0,88	0,83	0,78	0,73	0,68
25	80	1,24	1,20	1,17	1,13	1,09	1,04	1,00	0,95	0,90	0,85	0,80	0,74
25	70	1,29	1,24	1,20	1,15	1,11	1,05	1,00	0,94	0,88	0,81	0,74	0,67
15	65	1,18	1,14	1,10	1,05	1,00	0,95	0,89	0,84	0,77	0,71	0,63	0,55
25	65	1,32	1,27	1,22	1,17	1,12	1,06	1,00	0,94	0,87	0,79	0,71	0,61
15	60	1,20	1,15	1,12	1,06	1,00	0,94	0,88	0,82	0,75	0,67	0,57	0,47
25	60	1,36	1,31	1,25	1,20	1,13	1,07	1,00	0,93	0,85	0,76	0,66	0,54
15	55	1,22	1,17	1,12	1,07	1,00	0,93	0,86	0,79	0,71	0,61	0,50	0,36
25	55	1,41	1,35	1,29	1,23	1,15	1,08	1,00	0,91	0,82	0,71	0,58	0,41
15	50	1,25	1,20	1,14	1,07	1,00	0,93	0,84	0,76	0,66	0,54	0,37	—
25	50	1,48	1,41	1,34	1,26	1,18	1,09	1,00	0,89	0,78	0,63	0,45	—

Key: (1). Maximum temperature of medium, °C. (2). Specified temperature of conductors, °C. (3). Correction factors at actual

temperature of medium, °C.

P-11.7. Sizes/dimensions of end fittings of power cables from epoxy trovelling compound [11-1].

(1) Тип заделки	(2) Сечение жил кабеля, мм², для номинальных напряжений			(3) Размеры заделок, мм (рис. 11-2)				
	(5) 1 кв	(5) 6 кв	(5) 10 кв	D	h	c	n	(4) a¹ (не менее)
ЭЭ-1	2,5—10	—	—	48	105	80	20	40
ЭЭ-2	16—35	10	—	58	110	80	20	40
ЭЭ-3	50—70	16—35	—	67	130	80	20	10
ЭЭ-4	95	50	16—35	71	135	80	20	40
ЭЭ-5	120—150	70—95	50—70	82	155	85	20	45
ЭЭ-6	185	120—150	95—120	88	165	85	25	15
ЭЭ-7	240	185	150	96	185	90	25	50
ЭЭ-8	—	240	185—240	105	200	90	25	50

Key: (1). Type of closing. (2). Section of strands of cable, mm², for nominal voltages. (3). Sizes/dimensions of closings, mm (Fig. 11-2). (4). a¹ is not less.

FOOTNOTE ¹. For obtaining sufficient airtightness of closing the size/dimension of "a" (value of the overlap by the closing of lead covering) must strictly be observed. ENDFOOTNOTE.

(5). kV.

P-12. Fundamental characteristics of safety fuses by voltage are above 1000 V.

(1) Тип	(2) Номинальное напряжение, кв	(3) Номинальный ток, а	(4) Предельный ток отключения*, ка
(5) *Силовые предохранители*			
(6) а) Для внутренней установки			
ПК-3	3	30, 100, 200, 400	40
ПК-6	6	30, 75, 150, 300	20
ПК-10	10	30, 50, 100, 200	12
ПК-35	35	10, 20, 40	3,5
(7) б) Для наружной установки			
ПК-6Н	6	30	20
ПК-10Н	10	30	12
ПРН-35	35	2—7,5	0,06
ПСН-10	10	7,5—100	12
ПСН-35	35	7,5—100	8
ПСН-110	110	До 50	8
(8) *Предохранители к трансформаторам напряжения*			
(6) а) Для внутренней установки			
ПКТ-10	3 (8a) и 6	(9) Не нормируется	(10) Не ограничивается
	10	(11) То же	50
ПКТУ-10	10	"	(10) Не ограничивается
ПКТ-20	15	"	(10) Не ограничивается
	20	"	30
ПКТУ-20	20	"	(10) Не ограничивается
ПКТ-35	35	"	17
ПКТУ-35	35	"	(10) Не ограничивается
(7) б) Для наружной установки			
ПРТН-35**	35	0,3—1	—

Key: (1). Type. (2). Nominal voltage, kV. (3). Rated current, a. (4). Limiting current of cutoff/disconnection [1], kA.

FOOTNOTE [1]. Symmetrical (periodic) component of short-circuit current. ENDFOOTNOTE.

(5). Power safety devices/fuses. (6). a) for internal installation. (7). b) for external installation. (8). fuses to voltage transformers. (8a). and. (9). It is not normalized. (10). It is not

limited. (11). Then.

FOOTNOTE [2]. It is adapted only with the current-limiting additional resistance of the type SDN-35. ENDFOOTNOTE.

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P-13. Fundamental characteristics of disconnector switches.

(1) Тип разъединителя	(2) Номинальное напряжение, кв	(3) Номинальный ток, а	(4) Ток электродинамической устойчивости (амплитудное значение) $i_{макс}$, ка	(5) Ток термической устойчивости, десятисекундный I_{10}, ка	(6) Тип привода
		(7) Для внутренней установки			
РВО-6/400, РВО-10/400	6 и (8) 10	400	50	10	(9) Управление штангой
РВО-6/600; РВО-10/600	6 и 10	600	60	14	
РВ (РВФ, РВЗ)-6/400	6	400	50	10	
РВ (РВФ, РВЗ)-6/600	6	600	60	14	
РВ (РВФ, РВЗ)-10/400	10	400	50	10	ПР-2
РВ (РВФ, РВЗ)-10/600	10	600	60	14	
РВ (РВФ)-6/1000 и 10/1000	6 и 10	1 000	120	28	ПР-3
РЛВН-10/2000	10	2 000	86,5	36	
РЛВН-10/3000	10	3 000	140	50	ПР-3; ПЧ-50
РВК-10/3000	10	3 000	200	60	ПЧ-50
РВК-10/4000	10	4 000	200	65	МРВ
РВК-10/5000	10	5 000	200	70	
РЛВН-20/400	20	400	45	10	ПР-3
РВК-20/5000	20	5 000	200	70	ПЧ-50
РВК-20/6000	20	6 000	250	75	МРВ
РВК-20/7000	20	7 000	320	85	МРВ
РЛВН-35/400	35	400	50	10	
РЛВН-35/600	35	600	50	14	ПР-3
РЛВН-35/1000	35	1 000	80	20	
		(10) Для наружной установки			
РЛНД-10/200	10	200	15	4	
РЛНД-10/400	10	400	25	6	ПРН-10М
РЛНД-10/600	10	600	35	9	
РОН-10/4000	10	4 000	250	95	ПЧН
РЛНД-35/600					ПРН-110М
РЛНД1-35/600	35	600	80	12	ПРНЗ-35М
РЛНД2-35/600					ПРН-220М
РЛНД-35/1000					ПРН-110М
РЛНД1-35/1000	35	1 000	80	15	ПРНЗ-35М
РЛНД2-35/1000					ПРН-220М
РОНЗ-35Д/2000	35	2 000	120	29	ПРНЗ-35М
РЛНД-110/600					ПРН-110М
РЛНД1-110/600	110	600	80	12	ПРНЗ-35М
РЛНД2-110/600					ПРН-220М
РЛНД-110/1000					ПРН-110М
РЛНД1-110/1000	110	1 000	80	15	ПРНЗ-35М
РЛНД2-110/1000					ПРН-220М
РОН-110/2000; РОНЗ-110/2000	110	2 000	80	25	ПРН-220; ПДН-220
РЛНО-110М/600	110	600	50	10	
РЛНО-110М/1000	110	1 000	50	15	ПЧН
РЛНЗ-154М/600	154	600	50	10	ПЧНЗ
РЛНЗ-220М/600	220	600	50	10	ПЧНЗ
РЛНЗ-220/1000	220	1 000	50	10	ПРН-220;
РОНЗ-220/2000	220	2 000	80	25	ПДН-220
РОНЗ-500/2000	500	2 000	—	—	(11) Рабочих ножей ПДН-400 (12) Ножей заземления ПРНЗ-500
РНД-500/2000	500	2 000	—	—	(13) Электродвигательный привод на каждую фазу

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Continuation Table P-13.

(1) Тип разъединителя	(2) Номинальное напряжение, кв	(3) Номинальный ток, а	(4) Ток электродинамической устойчивости (амплитудное значение) $I_{макс}$, ка	(5) Ток термической устойчивости, десятисекундный I_{10}, ка	(6) Тип привода
	(14) *Отделители трехполюсные*				
ОД-35/600	35	600	80	10	ШПО
ОД-110/600	110				
ОД-154/600	154				
НД-220/600	220				
	(15) *Заземлитель однополюсный*				
ЗОН-110	110	400	—	(16) 4 (ток однофазного к. з. в течение 10 сек)	ПРН-110
	(17) *Короткозамыкатели*				
			(18) Ток замыкания (амплитудное значение), ка	(19) Ток термической устойчивости, двухсекундный I_2, ка	
КЗ-35 (двухполюсный) (20)	35	—	42	18	ШПК
КЗ-110 (однополюсный) (21)	110	—	34	15	ШПК
КЗ-154 (однополюсный) (21)	154	—			
КЗ-220 (однополюсный) (21)	220	—			

Notes:

1. Disconnector switcnes of tne type RVO - unipolar.

2. Disconnector switches of type RV - tripolar, on six support insulators. Disconnector switches of the type RVP are manufactured on three supporting and three bushings (passage can be provided from any

side of knives) or on six bushings (F - figured performance of disconnector switch). Disconnector switches of the type RVZ have knives of the groundings which can be established/installed from any side of the working knives; for management are used two drives of the type PR-2: one for workers, and by the second for the grounding knives.

3. Disconnector switches of types RLVIII and RVK are manufactured only on stand-off insulators and of grounding knives they do not have.

4. Table gives values of currents of electrodynamic stability of disconnector switches of type RVK when distance a between axes of adjacent poles of disconnector switch and distance 1 between axes of stand-off insulator of disconnector switch and nearest to it stand-off insulator of busbar/tire comprise: for disconnector switches of types RVK-10/3000 and 10/4000 a=500 mm and l=500 mm, for disconnector switch of type RVK-10/5000 a=600 mm and l=550 mm, for disconnector switches of types RVK-20/5000, 20/6000 and 20/7000 a=700 mm, l=850 mm. At smaller values of a and high values l the strength of current of the electrodynamic stability of disconnector switch descends. The corresponding data are given in catalogues or information materials of plants.

5. Disconnector switches of types RLND, RON and RLNO of grounding knives do not have. The disconnector switches of types RLND1 have the grounding knives only from one side (any) of working knives, while those of types RLND2 - from two sides of working knives. The disconnector switches of types RONZ and RND-500 have knives of grounding either with one (any), or from two sides of working knives. The disconnector switches of the types RLNZ-154 and RLNZ-220M have grounding knives only d of one (any) side of working knives.

6. Disconnector switches of types RLND (1, 2)-35 during use for cutoff/disconnection of running-light currents of power transformers in power to 20 MVA (see Chapter 16) one should install with distance between phases (poles) not less than 2 m (instead of 1.2 m in presence in circuit of switch). During vertical installation these disconnector switches can disconnect the running-light current of transformers whose power is not more than 3.2 MVA (information communication/report of the Electroheat-plan of 2 February, 1959, No 11E).

The disconnector switches of types RLND (1,2)-110 during use for the cutoff/disconnection of the running-light currents of power transformers in power to 31.5 MVA (see Chapter 16) during horizontal installation must have a distance between phases (poles) not less

than 3 m (instead of 2-2.5 m in the presence in circuit of switch).

7. Drives of disconnector switches of types PR, PRN, PRNZ - manual lever; types PCh and PChN - manual worm; type MRV - electric-motor for internal installation; type PDN - electric-motor for external installation.

8. Drive of separator of type ShPO is intended for automatic cutoff/disconnection of separator and its manual start; this drive is designed on basis of cargo drive of type PG-10.

9. Drive shorting devices of type ShPK serves for manual cutoff/disconnection of shorting device and for automatic breaking as its spring mechanism from relaying; spring mechanism is started with manual cutoff/disconnection of shorting device.

10. Ground electrodes are let out in two versions: a) for grounding of neutral particles of power transformers, which have in neutral particle current transformer for protection from single-phase short circuits, and b) for grounding of neutral particles of

transformers without inclusion into neutral particle of current transformer, and also for grounding of busbars/tires of open distributors.

Key: (1). Type of disconnector switch. (2). Nominal voltage, kV. (3). Rated current, a. (4). Current of electrodynamic stability (amplitude value) i_{make}, kA. (5). Current of thermal resistance, ten-second I_{10}, kA. (6). Type of drive. (7). For internal installation. (8). and. (9). Management of rod. (10). For external installation. (11). Working knives. (12). Knives of grounding. (13). Electric-motor drive to each phase. (14). Separators (tripolar. (15). Ground electrode (unipolar. (16). current single-phase short circuit during 10 s. (17). Shorting devices. (18). Current of closing/shorting (amplitude value), kA. (19). Current of thermal resistance, two-second I_2, kA. (20). double-pole. (21). unipolar.

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P-14. Fundamental characteristics of high-voltage switches.

P-14.1. Switches for internal installation to nominal voltages to 35 kV inclusively.

(1) Тип выключателя	(2) Номинальное напряжение, кв	(3) Максимальное рабочее напряжение, кв	(4) Номинальный ток, а	(5) Ток электродинамической устойчивости (амплитудное значение) $I_{макс}$, ка	(6) Ток термической устойчивости, десятисекундный I_{10}, ка	(7) Ток отключения, ка, при напряжении, кв						(8) Мощность отключения, Мва, при напряжении, кв						(9) Тип привода	(10) Вес, кг	
						3	6	10	13,6	20	35	3	6	10	13,8	20	35		(11) без масла	(12) масла
ВМЭ-6	6 10	6,9 11,5	200 200	16,8 14,5	6 3,9	3,3 —	1,4 4,8	— 2,9	— —	— —	— —	17 —	15 50	— 50	— —	— —	— —	(13) ПРБА и ПМ-10	50	15
ВМБ-10	10	11,5	200 400 600 1 000	25	6 10	9,7	9,7	5,8	—	—	—	50	100	100	—	—	—	ПРА-10, ПРАМ-10, ПС-10М	120 125 100 110	50
ВМГ-133I ВМГ-133II ВМГ-133III	10 10 10	11,5 11,5 11,5	600 600 1 000	52	14	20	20	11,6 20 20	—	—	—	100	200	200 350 350	—	—	—	ПРБА, ПГ-10, ПГМ-10, ПП-10, ППМ-10, ПС-10М	170 190 200	5 10 10
ВМП-6Т	6,6	6,9	600 1 000	45	12,5	—	17,5*	—	—	—	—	—	200*	—	—	—	—	(14) То же	200	4,5
МГГ-10	10	11,5	2 000 3 000	75	21	29	29	29	—	—	—	150	300	500	—	—	—	ПЭ-2	550 600	20 20
МГГ-10-750	10	11,5	2 000 3 000 4 000	120	30 30 42	42	42	42	—	—	—	225	450	750	—	—	—	ПЭ-21	700	25
МГ-10	10	11,5	5 000	300**	70	105	105	105	—	—	—	550	1 100	1 800	—	—	—	ПС-31, ПВ-30***	2 100	55
МГ-20	20	23	6 000	300**	85	105	105	105	105	87	—	550	1 100	1 800	2 500	3 000	—	ПС-31, ПВ-30***	2 400	55
МГ-35В	35	40,5	600 1 000	25	7	—	—	—	—	—	8,2	—	—	—	—	—	500	ПС-20	930	36
ВГ-10	10	11,5	400	52	10	—	20	17,5	—	—	—	—	200	300	—	—	—	ПР-3В, ПС-10М	300	—
ВВ-15	13,8	13,8	5 500	250	75	—	—	100	85	—	—	—	—	1 750	2 000	—	—	(15) Воздушное управление	3 000	—

Key: (1). Type of switch. (2). Nominal voltage, kV. (3). Maximum are working voltage, kV. (4). Rated current, a. (5). Current of electrodynamic stability (amplitude value) $I_{макс}$, kA. (6). Current of

thermal resistance, ten-second I_{20}. (7). Current of cutoff/disconnection as with voltage, kV. (8). Power cutoff/disconnection MVA, with voltage, kV. (9). Type of drive. (10). weight, k. (11). bev of oil. (12). oil. (13). and. (14). Then. (15). Air management.

FOOTNOTE [1]. With voltage 6.6 kV.

The mechanical stability of these switches, as earlier of let out switches of types MGG-229, MGG-29 and other similar constructions/designs, in essence is ensured by the mechanical strength of the busbars/tires, connected up switch. Therefore independent of the value of the operating current of circuit it is necessary to provide for the intensive construction/design of busbars/tires in the cells of these switches (to use multiband or box busbars/tires on the dual insulators of types (OMD-10 and OMD-20 or OD-10 and OD-20), being guided by following materials of the Electroheat-plan: by directive indications No 1112-3 of April 1956 by the information communication/report No 23-E of April 1958.

[3]. Pneumatic drive.

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P-14.2. Switches for external installation.

(1) Тип выключателя	(2) Номинальное напряжение, кв	(3) Максимальное рабочее напряжение, кв	(4) Номинальный ток, а	(5) Ток электродинамической устойчивости (амплитудное значение) $i_{макс}$, ка	(6) Ток термической устойчивости, десятисекундный I_{10}, ка	(7) Ток отключения, ка, при напряжении, кв: 35	110	154	220	400	500	(8) Мощность отключения, Мва, при напряжении, кв: 35	110	154	220	400	500	(9) Тип привода	(10) Вес, кг: (11) без масла	(12) масла
ВМ-35						6,6	—	—	—	—	—	400	—	—	—	—	—	ШНР-35	900	300
ВМД-35-600	35	40.5	600	17,3	7,1	10	—	—	—	—	—	600	—	—	—	—	—	ШПС-10	1 025	300
ВМР-35-600						10	—	—	—	—	—	600	—	—	—	—	—	ШПР	—	—
МКП-35	35	40.5	600	30	9	12,5	—	—	—	—	—	750	—	—	—	—	—	ШПЭ-2	2 600	800
			1 000	45	11,7	16.5	—	—	—	—	—	1 000	—	—	—	—	—			
МКП-35-1500	35	40.5	1 000	63	18	24,7	—	—	—	—	—	1 500	—	—	—	—	—	ШПЭ-31	3 550	800
МКП-110М	110	121	600	50	13	—	18,4	—	—	—	—	—	3 500	—	—	—	—	ШПЭ-33	9 630	8 500
			1 000																	
МКП-220-5	220	242	600	50	13	—	—	—	13,2	—	—	—	—	—	5 000	—	—	ШПЭ-42	42 000	48 000
			1 000																	
МКП-500*	500	525	1 000	50	13	—	—	—	—	—	13,9	—	—	—	—	—	12 000	ШПЭ-504	80 000	88 000
МГ-35	35	40.5	600	25	7	8,2	—	—	—	—	—	500	—	—	—	—	—	ШПС-20	930	36
МГ-110	110	121	600	49	14	—	13,2	—	—	—	—	—	2 500	—	—	—	—	ШПС-30	3 000	600
ВВН-35	35	40,5	600	50	21	16,5	—	—	—	—	—	1 000	—	—	—	—	—		1 200	—
			1 000																	
ВВН-35/2000	35	40,5	2 000	84	24	33	—	—	—	—	—	2 000	—	—	—	—	—		2 500	—
ВВН-110/800-4000	110	121	800	55	15	—	21	—	—	—	—	—	4 000	—	—	—	—		5 900	—
ВВН-110/2000-4000	110	121	2 000	55	15	—	21	—	—	—	—	—	4 000	—	—	—	—	(13)	5 900	—
ВВН-110/2000-6000	110	121	2 000	80	20	—	31,5	—	—	—	—	—	6 000	—	—	—	—	Воздушное	9 000	—
ВВН-154/800-6000	154	169	800	64	18	—	—	22,5	—	—	—	—	—	6 000	—	—	—	управление	7 900	—
ВВН-154/2000-6000	154	169	2 000	64	18	—	—	22,5	—	—	—	—	—	6 000	—	—	—		7 900	—
ВВН-220/1000-7000	220	242	1 000	55	12	—	—	—	18,4	—	—	—	—	—	7 000	—	—		20 000	—
ВВН-220/2000-7000	220	242	2 000	55	12	—	—	—	18,4	—	—	—	—	—	7 000	—	—		20 000	—
ВВН-220/2000-10000	220	242	2 000	70	15	—	—	—	26,2	—	—	—	—	—	10 000	—	—		~15 000	—
ВВ-400/2000-15	400	420	2 000	55	—	—	—	—	—	22	—	—	—	—	—	15 000	—		~50 000	—
ВВ-500	500	525	2 000	58,8	34*	—	—	—	—	—	23	—	—	—	—	—	20 000		57 000	—

Key: (1). Type of switch. (2). Nominal voltage, kV. (3). Maximum are working voltage, kV. (4). Rated current, a. (5). Current of electrodynamic stability (amplitude value) $I_{пикс}$ kA. (6). Current of thermal resistance, ten-second I_{10}, kA. (7). Current of cutoff/disconnection, kA, with voltage, kV. (8). Power of

cutoff/disconnection, MVA, with voltage, kV. (9). Type of drive. (10). Weight, kg. (11). without oil. (12). oil. (13). Air control.

FOOTNOTE [1]. One-second current. ENDFOOTNOTE.

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P-15. Fundamental characteristics of switches of load.

(1) Тип выключателя	(2) Номинальное напряжение, кв	(3) Номинальный ток, а	(4) Предельный ток отключения (нагрузки), а	(5) Ток электродинамической устойчивости (амплитудное значение) $i_{макс}$, ка	(6) Ток термической устойчивости, десятисекундный I_{10}, ка	(7) Тип привода	(8) Вес выключателя, кг
ВН-16						ПР-17	36
ВНП-16	6	400	400	25	6	ПРА-17	50—64
ВНП-17	10	200	200			ПС-10М	

Note. Switches of types GNP-16 and GNP-17 are executed on overall frame with safety devices/fuses of the type PK. A switch of the type GNP-17 has a device/equipment, which automatically disconnects it with burnout by melting the insert of any of three safety devices/fuses; it is adapted with the drives of types PRA-17 and PS-10M.

Key: (1). Type switches. (2). Nominal voltage, kV. (3). Rated current, a. (4). Limiting current of cutoff/disconnection (load), a. (5). Current of electrodynamic stability (amplitude value) $i_{макс}$ kA. (6). Current of thermal resistance, ten-second I_{10}, kA. (7). Type of drive. (8). Weight of switch, kg.

P-16. Fundamental characteristics of electromagnetic actuators to switches.

(1) Выключатель			(2) Установившиеся токи, потребляемые приводами, а			
(3) Тип	(4) Номинальный ток, а	(5) Тип привода	(6) Включение при номинальном напряжении		(7) Отключение при номинальном напряжении	
			110 в (8)	220 в (8)	110 в (8)	220 в (8)
ВН-16	200 и 400	ПС-10М	76	34	5	2,5
ВМБ-10	200 и 1 000	ПС-10М	157	78,5	5	2,5
ВМГ-133	600 и 1 000	ПС-10М	195	97,5	5	2,5
ВМП-6Г	600 и 1 000	ПС-10М	—	—	—	—
МГГ-10	2 000 и 3 000	ПЭ-2	150	75	5	2,5
МГ-10	5 000	ПС-31	310	155	5	2,5
МГ-20	6 000	ПС-31	310	155	5	2,5
ВГ-10	400	ПС-10М	240	120	5	2,5
ВМ-35 ВМД-35-600 ВМР-35-600	600	ШПС-10	195	97,5	5	2,5
МКП-35	600 и 1 000	ШПЭ-2	160	80	5	2,5
МКП-35-1500	1 000	ШПЭ-31	248	124	10	5
МКП-110М	600	ШПЭ-33	488	244	10	5
МКП-220-5	600	ШПЭ-42	480	240	10	5
МКП-500	1 000	ШПЭ 501	—	—	—	—
МГ-35В	600	ПС-20	150	75	5	2,5
МГ-35	600	ШПС-20	132	66	5	2,5
МГ-110	600	ШПС-30	366	183	8,2	4,1

Note. Process/operations by electromagnetic actuators are permitted when the conducted/supplied to drive voltage of the source of direct current is located within the limits: for clutch magnets 80-110o/o, and for disconnecting electromagnets 65-120o/o of nominal voltage of drive.

Key: (1). Switch. (2). Steady currents, consumed by drives, a. (3). Type. (4). Rated current, a. (5). Type of drive. (6). Start with nominal voltage. (7). Cutoff/disconnection with nominal voltage. (8). In. (9). and.

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P-17. Fundamental characteristics of transformers of current with voltage above 1000 V.

(1) Тип	(2) Номинальное напряжение, *кв*	(3) Номинальный первичный ток, *а*	(4) Классы точности сердечников	(5) Электродинамическая устойчивость (кратность) $K_{дин}$	(6) Термическая устойчивость (односекундная кратность) $K_{1сек}$	(7) Характеристики сердечников: (8) Класс сердечника	(9) Мощности сердечников, *ва*, при классах точности: 0,5	1	3	10	(10) Примечание
				(11) *Для внутренней установки*							(12) См. примечание 1
ТПФМ	10	5—400	0,5; 0,5/0,5; 0,5/3; 1; 1/1; 1/3;3	165 250	75 80	0,5 1 3	15 — —	30 15 —	75 40 30	— — 60	(13) См. примечания 2, 3 и 4
ТПФМУ	10	5—300 5—200	0,5; 0,5/0,5; 0,5/3; 1; 1/1; 1/3 3	250 500	80 240						(14) То же

Continuation table P-17.

TABLE 17.

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1 Тип	2 Номинальное напряжение, *кв*	3 Номинальный первичный ток, *а*	4 Классы точности сердечников	5 Электродинамическая устойчивость (кратность) $K_{дин}$	6 Термическая устойчивость (односекундная кратность) $K_{1сек}$	7 Характеристики сердечников: 8 Класс сердечника	9 Мощности сердечников, *ва*, при классах точности: 0,5	1	3	10	10 Примечание
ТПОР	10	600	0,5	150	80						12 См. примечание 5
		750	0,5	133	80						
		1 000	0,5	100	80						
		1 500	0,5	66	80						
		750	0,5/0,5	105	80						
		1 000	0,5/0,5	90	80						
		1 500	0,5/0,5	66	80						
		600	0,5/3	130	80						
		750	0,5/3	120	80						
		1 000	0,5/3	90	80						
		1 500	0,5/3	66	80						
		600	1	166	80						
		750	1	133	80						
		1 000	1	100	80						
		600	1/1	130	80						
		750	1/1	120	80						
		1 000	1/1	100	80						
		600	1/3	150	80						
		750	1/3	120	80						
		1 000	1/3	100	80						
		600	3	166	80						
		750	3	133	80						
		1 000	3	100	80	0,5	20	50	150	—	
		1 500	3	66	80	1	—	20	50	—	
						3	—	—	50	100	
ТПОФУ	10	600	0,5	150	120						
		750	0,5	133	120						
		1 000	0,5	100	120						
		750	0,5/0,5	105	120						
		1 000	0,5/0,5	90	120						
		600	0,5/3	130	120						
		750	0,5/3	120	120						
		1 000	0,5/3	90	120						
		400	1	225	120						
		600	1	166	120						
		750	1	133	120						
		1 000	1	100	120						
		600	1/1	130	120						
		750	1/1	120	120						
		1 000	1/1	100	120						
		400	1/3	200	120						
		600	1/3	150	120						
		750	1/3	120	120						
		1 000	1/3	100	120						
		400	3	250	240						
		600	3	166	240						
		750	3	133	240						
ТПШФА	10	2 000; 3 000, 4 000; 5 000;	0,5/0,5;	—	75	0,5	30	75	150	—	13 См. примечания 6 и 7
ТПШФА	20	2 000; 3 000; 4 000; 5 000	0,5/3			3	—	—	50	100	
ТПШФ	20	6 000	0,5/0,5	—	75	0,5	50	100	—	—	14 То же
ТКЛ и ТПЛ	10	5—200	0,5; 0,5/Р	250	90	0,5	10	20	—	—	13 См. примечания 2 и 8
		300		175	90	Р	15	25	30	—	
		400		165	70						
ТКЛУ	10	10—100		250	120						
ТПЛУ	10	10—100		250	120						

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Continuation Table P-17.

Тип	Номинальное напряжение, кв	Номинальный первичный ток, а	Классы точности сердечников	Электродинамическая устойчивость (кратность) $K_{дин}$	Термическая устойчивость (односекундная кратность) $K_{1сек}$	Характеристики сердечников: Класс сердечника	Мощности сердечников, ва, при классах точности: 0,5	1	3	10	Примечание
ТПОЛ	10	600; 800 1 000 1 500	0,5; 0,5/Р	160 140 90	65 55 36	0,5 Р	10 15	20 25	— 30	— —	
ТПОЛ	35	400; 600; 800; 1 000, 1 500	0,5/1; 0,5/Д; 1/Д	$i_{макс}$ = 150 ка	80	0,5 1	20 —	— 20	— —	— —	
ТПШЛ	10	2 000; 3 000; 4 000; 5 000	0,5/Д	—	70	0,5	20	30	60	—	
ТШЛ	20	6 000; 8 000; 10 000	0,5/Д	—	—	0,5	20	—	—	—	
				Для наружной установки							
ТФН	35	15—1 000	0,5/3	100	65	0,5 3	50 —	100 —	200 50	— 100	См. примечание 2
ТФНУ	35	15—600	0,5/1	150	90	0,5 1	30 —	75 30	125 75	— —	
ТФНД	35	15—800 1 000	Д/0,5 Д/0,5	150 100	65 65	0,5 Д	30 —	75 30	125 75	— —	
ТФНУД	35	15—600	Д/0,5	150	90						
ТФНД	35	15—600 800; 1 500 1 000; 2 000	Д/Д/0,5 Д/Д/0,5 Д/Д/0,5	150 100 50	65 65 65	0,5 Д	30 50	60 100	— —	— —	
ТФНУД	35	15—600	Д/Д/0,5	150	90						
ТФН ТФНД	110 110	50—600 50—600	0,5/1 Д/1	150 150	75 75	0,5 1 Д	30 — —	60 30 30	150 100 100	— — —	
ТФНД	110	50—600	Д/Д/0,5	150	75	0,5 Д№1 Д№2	30 60 30	100 100 60	— — —	— — —	
ТФНД	110	750—2000	Д/Д/0,5	75	60	0,5 Д	20 20	50 50	— —	— —	
ТФНД	154	600—1 200	Д/Д/0,5	50	60	0,5 Д	40 50	100 100	— —	— —	
ТФНД	220	300—1 200	Д/Д/Д/0,5	60	60	0,5 Д № 1 и 2 Д № 3	30 50 30	75 100 75	— — —	— — —	

Notes:

1. For current transformers of internal installation are given the characteristics only of measuring cores.

2. Scale of nominal primary currents for current transformers: 5; 10; 15; 20; 30; 40; 50; 75; 100; 150; 200; 300; 400; 500; 600; 750; 800; 1000; 1200; 1500; 2000; 3000; 4000; 5000; 6000; 8000; 10000; 12000; 15000 a. The separate types of transformers of current are manufactured to the corresponding rated currents in the limits, indicated in table.

3. For current transformers of types TPF and TPFU electrodynamic stability is shown for all transformers with primary current 20a and more. Current transformers to nominal currents below 20A have smaller electrodynamic stability.

4. For current transformers of type TPF and TPFU efforts/forces to outputs of primary windings must not exceed:

for transformers with one core: 150 kgf from the side L_1 and 140 kgf from the side L_2;

for transformers with two cores; 150 kgf from the side L_1 and 75

kgf from the side L_2.

5. For current transformers of type TPOF and type TPOFU data of dynamic stability are real with distance between phases a=40 cm and with distance of nearest stand-off insulator l=50 cm. With the distance between phases, different from 40 cm, dynamic stability changes in relation $\sqrt{\frac{a}{40}}$. With distance of the nearest stand-off insulator l=20 cm dynamic stability rises by 15o/o, with l=100 cm - dynamic stability decreases by 20o/o.

6. Permissible efforts/forces to heads of insulators:

current transformers of type TPShFA10 from the side L_1 of 900 kgf and from the side L_2 of 425 kgf;

current transformers of type TPShFA20 from the side L_1 of 650 kgf and from the side L_2 of 400 kgf;

current transformers of type TPShF20 from the side L_1 of 700 kgf and from the side L_2 of 400 kgf.

7. Thermal resistance of busbar/tire current transformers is determined by stability of busbars/tires, passing through transformer. The indicated in table one-second thermal resistance

(multiplicity) is related on secondary winding of current transformers of this type.

8. Effort/force on output of primary winding must not exceed.

for current transformers of types TKL, TKLU, TPL and GPLU of 13 kgf;

for current transformers of the type TPOL of 150 kgf.

Key: (1). Type. (2). Nominal voltage, kV. (3). Nominal primary current, a. (4). Classes of precision of cores. (5). Electrodynamic stability (multiplicity). (6). Thermal resistance (one-second multiplicity). (7). Characteristics of cores. (8). Class of core. (9). Power of cores, VA, with classes of precision. (10). Note. (11). For internal installation. (12). See note 1. (13). See notes by 2, 3 and 4. (14). Then. (15). For external installation.

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P-18. Fundamental characteristics of voltage transformers.

(1) Тип трансформатора напряжения	(2) Номинальный коэффициент трансформации, в/в	(3) Номинальная мощность (ва) при классах точности 0,5	1	3	(4) Максимальная мощность, ва
(9) *Однофазные трансформаторы с воздушным охлаждением*					
НОС-0,5	380/100; 500/100	25	40	100	200
НОСК-3	3 000/100	30	50	120	240
НОСК-6	6 000/100	50	80	200	400
(11) *Трехфазные трансформаторы с воздушным охлаждением*					
НТС-0,5	380/100; 500/100	50	80	200	400
(12) *Однофазные трансформаторы с масляным охлаждением*					
НОМ-6	3 000/100	30	50	120	400
	6 000/100	50	80	200	600
НОМ-10	10 000/100	80	150	320	720
НОМ-15	13 800/100; 15 000/100; 18 000/100	80	150	320	840
НОМ-35*	35 000/100	150	250	600	1 200
ЗНОМ-35-54*	$\frac{35\,000}{\sqrt{3}} / \frac{100}{\sqrt{3}} / \frac{100}{3}$	150	250	600	1 200
НКФ-110* (14) (каскадный)	$\frac{110\,000}{\sqrt{3}} / \frac{100}{\sqrt{3}} / 100$	—	500	1 000	2 000
НКФ-220*	$\frac{154\,000}{\sqrt{3}} / \frac{100}{\sqrt{3}} / 100$; $\frac{220\,000}{\sqrt{3}} / \frac{100}{\sqrt{3}} / 100$	—	500	1 000	2 000
НКФ-400*	$\frac{400\,000}{\sqrt{3}} / \frac{100}{\sqrt{3}} / 100$	—	500	1 000	2 000

(5) Тип трансформатора напряжения	(6) Номинальный коэффициент трансформации, в/в	(7) Номинальная мощность (ва) при классах точности 0,5	1	3	(8) Максимальная мощность, ва
(10) *Трехфазные трансформаторы с масляным охлаждением*					
НТМК-6-48	3 000/100	50	80	200	400
	6 000/100	80	150	320	640
НТМК-10	10 000/100	120	200	480	960
НТМИ-6 (пятистержневой) (13)	$3\,000/100/\frac{100}{3}$	50	80	200	400
	$6\,000/100/\frac{100}{3}$	80	150	320	640
НТМИ-10	$10\,000/100/\frac{100}{3}$	120	200	480	960
НТМИ-18	$13\,800/100/\frac{100}{3}$; $15\,000/100/\frac{100}{3}$; $18\,000/100/\frac{100}{3}$	120	200	480	960

Notes: 1. Asterisk (*) noted voltage transformers for external installation.

2. Voltage transformer of type ZNOM-35-54 is intended for networks/grids by voltage 35 kV, of workers with ungrounded neutral

particles or with neutral particles, grounded through arc-suppressing coils: can be used for inspection states of insulation of phases with respect to earth/ground and simultaneously for nourishment of any measuring meters, switching on wattmeter and counters (54 - year of development of construction/design).

Key: (1). Type of voltage transformer. (2). Nominal transformation ratio, V/V. (3). Nominal power (VA) with classes of precision. (4). Maximum power, VA. (5). Type of voltage transformer. (6). Nominal transformation ratio, V/V. (7). Nominal power (VA) with classes of precision. (8). Maximum power, VA. (9). Single-phase transformers with ventilation. (10). Three-phase oil transformers. (11). Three-phase transformers with ventilation. (12). Single-phase oil transformers. (13). five-rod. (14). cascade.

P-19. Characteristics of shield electric measuring instruments.

Название прибора	Тип прибора	Система прибора	Потребляемая мощность, ва	cos φ	Примечание
Амперметр	ЭА-2	Электромагнитная	1,73	—	
Вольтметр	ЭВ-2	То же	7,2	1	
Ваттметр	ФДВА-2				
Вольтамперметр реактивный	ФДВР-2	Ферродинамическая	1,8	1	Параллельная
Ваттметр — вольтамперметр реактивный (с переключением)	ФДВАР-2		1,4	—	Последовательная
Фазометр	Д342	То же	0,93 3,25	1 —	Параллельная Последовательная
Счетчик для трехпроводных сетей (двухэлементный)	ИТ	Индукционная	1,75	0,38	Параллельная
Счетчик для четырехпроводных сетей (трехэлементный)	ТЧ	То же	0,525	—	Последовательная
Счетчик вольт-ампер-часов реактивный для трех- и четырехпроводных сетей	ИТР	То же	1,75 0,275 0,55 0,275	0,38 — — —	Параллельная Фаза A — Последовательная Фаза B — Последовательная Фаза C — Последовательная
Частотомер	Д340	Ферродинамическая	6,5	1	—
Амперметр самотекущий (регистрирующий)	Д33	То же	12	—	
То же, но с ускорением при авариях	Н325/1	Детекторная с магнитоэлектрическим измерителем	5	—	
Вольтметр самопишущий	Д33	Ферродинамическая	12,4	1	
То же, но с ускорением при авариях	Н325/1	Детекторная с магнитоэлектрическим измерителем	15	1	
Частотомер самопишущий	Н305	То же	15	1	
То же, но с ускорением при авариях	Н335	То же	15	1	
Ваттметр самопишущий Вольтамперметр реактивный самопишущий	Д33	Ферродинамический	8,3 5	1	Параллельная Последовательная
Синхроноскоп	Э32	Электромагнитная	1,5 7,6	0,87 0,92	Катушка, подключаемая к сети Катушка, подключаемая к синхронизируемому генератору

1. In the table are included electric measuring instruments, installed on panels and control panels of plant "Elektropul't".

2. Instruments of types EA-2, EV-2, FDVA-2, FDVR-2 and FDVAR-2 manufactures plant "Elektropul't".

3. Table shows approximate power coefficients, consumed by coils of instruments.

4. Voltampere meters reactive/jet of type FDVR-2 and phase meters of type D342 have three branch circuits, connected into star.

Key: (1). Name of instrument. (2). Type of instrument. (3). System of instrument. (4). Required power, VA. (5). Note. (6). Ammeter. (7). Electromagnetic. (8). Voltmeter. (9). Then. (10). Wattmeter. (11). Voltampere meter (reactive/jet). (12). Ferrodynamic. (13). Parallel. (14). Wattmeter - voltampere meter reactive/jet (with switching). (15). Sequential. (16). Phase meter. (17). Then. (18). Counter for three-wire networks/grids (two-element). (19). Induction. (20). Counter for four-wire networks/grids (tri-element). (21). Counter of volt-ampere-hours reactive/jet for three- and four-wire networks/grids. (22). Phase. (23). Frequency meter. (24). Ammeter, which auto/self-flows) recording). (25). Then, but with acceleration with emergencies. (26). Detector with magnetoelectric gauge. (27). Voltmeter, which records. (28). Frequency meter, which records. (29). Wattmeter, which records. (30). Voltampere meter reactive/jet recording. (31). Coil, connected to network. (32). Synchroscope. (33). Coil, connected to synchronized generator.

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REFERENCES

1-1. Промышленность СССР. Статистический сборник, ЦСУ, Госстатиздат, 1957.

1-2. СССР в цифрах, Статистический сборник, ЦСУ, Госстатиздат, 1958.

1-3. Ознобин Н. М., Электрификация СССР за 40 лет, изд. Академии наук СССР, 1958.

1-4. Крайз А. Г. и Сапожников А. В., Основные тенденции в современном трансформаторостроении, «Электричество», 1958, № 2.

2-1. Керцели Л. И. и Рыжкин В. Я., Тепловые электрические станции, изд. 2, Госэнергоиздат, 1956

2-2. Петров П. А., Ядерные энергетические установки, Госэнергоиздат, 1958.

3-1. Проф. Глазунов А. А., Неотложные задачи теории городских электрических сетей, «Электричество», 1956, № 7.

3-2. Правила технической эксплуатации электрических станций и сетей, МЭС СССР, Госэнергоиздат, 1953.

3-3. Сыромятников И. А., Применение напряжения 500 *кв* вместо 400 *кв*, «Электричество», 1957, № 11

3-4. Рокотян С. С., Перевод линий электропередачи 400 *кв* на 500 *кв*, «Энергетик», 1958, № 8

3-5. Правила техники безопасности при эксплуатации электроустановок электрических станций и подстанций, изд. 2, ТУ МЭС СССР, Госэнергоиздат, 1958.

3-6. Правила устройства электроустановок, разд. I, Общие правила, МЭС СССР, Госэнергоиздат, 1957.

3-7. Грудинский П. Г. и Сыромятников И. А., Электрические системы СССР за 40 лет. «Электрические станции», 1957, № 11.

3-8. Вейц В. И., Основы единой энергетической системы Европейской части СССР, «Электричество», 1957, № 1.

4-1. Электротехнический справочник, том II, коллектив авторов Московского энергетического института, изд. 2, Госэнергоиздат, 1955.

5-1. Бабиков М. А., Комаров Н. С., Сергеев А. С., Техника высоких напряжений, изд. 2, Госэнергоиздат, 1955.

5-2. Сборник директивных материалов, Электрическая часть, ТО МЭС СССР, Госэнергоиздат, 1950.

6-1. Руководящие указания по расчету токов короткого замыкания и выбору по режиму короткого замыкания аппаратуры и проводников электрических установок высокого напряжения, Технический отдел НКЭС СССР, Госэнергоиздат, 1944.

6-2. Пиотровский Л. М., Электрические машины, изд. 3, Госэнергоиздат, 1958.

6-3. Справочник по проектированию электрических станций и сетей. Часть электротехническая, разд. 2, вып. 1, Расчет токов короткого замыкания, Теплоэлектропроект, 1950.

6-4. Мансуров Н. Н. и Попов В. С., Теоретическая электротехника, изд. 7, Госэнергоиздат и Физматгиз, 1958.

Page 405.

6-5. Ульянов С. А., Короткие замыкания в электрических системах, изд. 4, Госэнергоиздат, 1952.

7-1. Рябков А. Я., Электрические сети, изд. 3, Госэнергоиздат, 1955.

7-2. Баптиданов Л. Н. и Тарасов В. И., Электрооборудование электрических станций и подстанций, том I, изд. 2, Госэнергоиздат, 1952.

8-1. Chase D. D., Garin A. N., Трансформаторы с расщепленной обмоткой, «Энергетическое обозрение», Электротехнический выпуск 1935, № 1.

8-2. Двоскин Л. И., Сдвоенные токоограничивающие реакторы, Госэнергоиздат, 1957.

9-1. Залесский А. М., Электрические аппараты высокого напряжения, Госэнергоиздат, 1957.

9-2. Электротехнический справочник, том I, коллектив авторов Московского энергетического института, изд. 2, Госэнергоиздат, 1955.

10-1. Справочник машиностроителя в шести томах, том 3, под редакцией С. В. Серенсена, изд. 2, Машгиз, 1956.

10-2. Институт Теплоэлектропроект, Выбор аппаратов и шин, Методика выбора шин специальных конструкций для установок 6—18 *кв* и шин для закрытых распределительных устройств 35—110 *кв*, 1953.

10-3. Институт Теплоэлектропроект, О механических характеристиках шин коробчатого сечения, Информационное сообщение № ЦПК-78 Э, 1958.

10-4. Решение ТУ МЭС об изменении § I-1-37 ПУЭ об окраске шин в распределительных устройствах, «Электричество», 1957, № 12.

11-1. Техническая документация на кабельные муфты, вып. VI, Концевые заделки из эпоксидного компаунда для трехжильных *кабелей с бумажной изоляцией* на напряжение 1—10 *кв* сечением от 2,5 до 240 *мм*², Госэнергоиздат, 1958.

12-1. Третьяк Г. Т. и Лысов Н. Е., Основы тепловых расчетов электрической аппаратуры, ОНТИ НКТП, 1935.

12-2. Бабиков М. А., Электрические аппараты, часть I, Госэнергоиздат, 1951.

12-3. Двоскин Л. И., О применении сварки шин в распределительных устройствах, «Электрические станции», 1956, № 8.

12-4. Кузнецов П. В., Монтаж распределительных устройств до 35 *кв*, Госэнергоиздат, 1957.

12-5. Решение ТУ МЭС № 29 от января 1956 г. о применении сварки шин, «Электрические станции», 1956, № 8.

12-6. Решение ТУ МЭС № 4/Э от марта 1954 г. о соединении шин давлением.

12-7. Бабиков М. А., Современные электрические аппараты высокого напряжения, Госэнергоиздат 1950.

13-1. Под редакцией проф. Глазунова А. А., Электрическая часть станций и подстанций, изд. 3, Госэнергоиздат, 1951.

14-1. Брон О. Б., Электрическая дуга в аппаратах управления, Госэнергоиздат, 1951.

14-2. НТО энергетической промышленности, Состояние и перспективы развития конструкций низковольтных аппаратов, Госэнергоиздат, 1959.

15-1. Бабиков М. А., Электрические аппараты, часть вторая, Аппараты низкого напряжения, Госэнергоиздат, 1956.

15-2. Брон О. Б., Низковольтные электрические аппараты, Всесоюзный институт научной и технической информации, 1958.

16-1. Техническое управление МЭС СССР, Решение № 20/Э от 30 декабря 1957 г. «О дальнейшем увеличении мощности трансформаторов, ток холостого хода которых можно отключать разъединителями», Госэнергоиздат, 1958.

16-2. Апраксин А. Н., Афанасьев В. В., Красногороднев С. А., Разъединители, Госэнергоиздат, 1952.

16-3. Под редакцией Л. И. Двоскина, Распределительные устройства с разъединителями новых типов, Госэнергоиздат, 1956.

17-1. Герценович С., Выключатели переменного тока высокого напряжения, Госэнергоиздат, 1958.

17-2. Выключатели высокого напряжения, вып. I, Баковые выключатели на напряжения 60—330 *кв*, Переводы статей под редакцией проф. Буткевича Г. В., Госэнергоиздат, 1958.

17-3. Гурвич В. Б. и Каплан В. В., Маломасляные подстанционные выключатели и приводы к ним, Госэнергоиздат, 1958.

17-4. Развитие конструкций подстанций высокого напряжения, под редакцией Л. И. Двоскина, Госэнергоиздат, 1957.

17-5. Цейров Е. М., Воздушные выключатели высокого напряжения, Госэнергоиздат, 1957.

17-6. Афанасьев В. В., Воздушные выключатели высокого напряжения, Госэнергоиздат, 1956.

19-1. Барзилович В. М., Высоковольтные трансформаторы тока, Госэнергоиздат, 1956.

19-2. Правила устройства электроустановок, раздел III, Защита и автоматика, МЭС СССР, Госэнергоиздат, 1957.

19-3. Чернобровов Н. В., Релейная защита, Госэнергоиздат, 1956.

19-4. Бачурин Н. И. и Грейнер Л. К., Трансформаторы *тока на особо высокие напряжения* (обзор конструкций на 275...400 *кв*), «Электричество», 1956, № 3.

22-1. Инструкция по эксплуатации и ремонту генераторов, ТУ МЭС СССР, Госэнергоиздат, 1952.

22-2. Комар Е. Г., Вопросы эксплуатации турбогенераторов, *Госэнергоиздат, 1950.*

22-3. Сыромятников И. А., Вопросы эксплуатации синхронных генераторов, Госэнергоиздат, 1948.

22-4. О тушении пожаров генераторов водой, Эксплуатационный циркуляр № 1, ТУ МЭС СССР, Госэнергоиздат, 1950.

22-5. Форсированное охлаждение турбогенераторов водородом, сборник статей, Госэнергоиздат, 1956.

22-6. Станиславский Л. Я., Турбогенераторы мощностью от 30 до 300 *Мвт* завода ХЭТЗ, «Электричество», 1958, № 3.

22-7. Суворов Н. П. и Калита В. Т., Освоение эксплуатации турбогенераторов с водородным охлаждением, Госэнергоиздат, 1954.

22-8. Комар Е. Г., Турбогенераторы с водородным охлаждением, Госэнергоиздат, 1948.

22-9. Иванов Н. П., Вопросы проектирования турбогенераторов с форсированным охлаждением, «Электричество», 1957, № 11.

22-10. Шмайн Ю. А., Применение выпрямителей для возбуждения синхронных машин (обзор), Информационные материалы № 15 ЦИНЭЛ, Госэнергоиздат, 1956.

22-11. Глух Е. М., Чалый Г. В., Эттингер Е. Л., Система ионного возбуждения гидрогенераторов, Сборник № 14 «Электросила», Госэнергоиздат, 1956.

22-12. Эксплуатационный циркуляр № 2/Э от 29 марта 1950, ТО МЭС СССР, «Электрические станции», 1950, № 5.

22-13. Решение № 10/Э от 30 марта 1956, ТУ МЭС СССР, «Электрические станции», 1956, № 6.

Page 406.

22-14. Брон О. Б. и Образцов В. А., Гашение поля синхронных машин, «Электричество», 1957, № 7.

22-15. Барзам А. Б., Системная автоматика, Госэнергоиздат, 1959.

22-16. Соловьев И. И., Автоматизация энергетических систем, изд. 2, Госэнергоиздат, 1956.

22-17. Баптиданов Л. Н. и Тарасов В. И., Электрооборудование электрических станций и подстанций, т. 1, Госэнергоиздат, 1947.

22-18. Сборник инструкций по включению на параллельную работу синхронных генераторов и компенсаторов способом самосинхронизации, ТУ МЭС СССР, Госэнергоиздат, 1955.

22-19. Элькинд Ю. М., Схемы и устройства для самосинхронизации синхронных машин, Госэнергоиздат, 1956.

22-20. Эксплуатационный циркуляр № Э-5/55, ТУ МЭС СССР, «Электрические станции», 1955, № 9.

23-1. Шницер Л. М., Дискуссия об учете нагрузочной способности при выборе трансформаторов, «Электрические станции», 1957, № 3.

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No typing.